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Proceedings of

National Conference on Concrete Road Building

Held at Chicago
February 12, 13, 14, 1914

Published under the direction
of the
Committee on Resolutions

PROCEEDINGS OF

[N]ational Conference on [C]oncrete Road Building

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February 12, 13, 14, 1914

Edited by the Secretary

SECRETARY'S OFFICE
208 SOUTH LA SALLE STREET
CHICAGO

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Dean, College of Engineering, University of Illinois.

PREFACE

The National Conference on Concrete Road Building had its origin in the following resolution, adopted at the annual meeting of the Directors of the Cement Products Exhibition Co. in Chicago, May 13, 1914:

> WHEREAS, the use of concrete in roads and streets has increased with singular rapidity during the past few years, and
>
> WHEREAS, there is a diversity of opinion and experience relative to costs, materials and the best methods of construction, and
>
> WHEREAS, the Cement Products Exhibition Co. is a co-operative educational organization for the development of concrete construction in every legitimate field through the agency of public expositions, meetings, and conferences; therefore be it
>
> RESOLVED, that the Executive Committee be and is hereby authorized and directed to call and convene a National Conference on Concrete Road Building of state highway commissioners, state engineers, county and township road officials, city engineers, park boards, officers and road committees of automobile clubs and associations, good roads organizations, agricultural societies, and others connected with or interested in the permanent improvement of public highways; said Conference to be held in the city of Chicago, Illinois, February 12, 13, and 14, 1914.

Under the authority of the above resolution, the President of the Cement Products Exhibition Co. invited a number of prominent representatives of educational institutions, agricultural organizations, engineering societies, good roads associations, highway officials, the engineering press, and others interested in the improvement of roads, to serve upon an Advisory Committee. A committee with the following personnel was formed:

ADVISORY COMMITTEE

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CHAPEL HILL, N. C.

DONALD D. PRICE, STATE ENGINEER,
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CHICAGO.

ALBERT REICHMANN, PRESIDENT,
WESTERN SOCIETY OF ENGINEERS,
CHICAGO.

F. W. RENWICK, PRESIDENT,
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HENRY E. RIGGS,
PROFESSOR OF CIVIL ENGINEERING,
UNIVERSITY OF MICHIGAN,
ANN ARBOR, MICH.

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INDUSTRIAL AND IMMIGRATION COMMISSIONER,
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HASTINGS, MICH.

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WISCONSIN HIGHWAY COMMISSIONERS' ASSOCIATION,
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ANDREW M. LAWRENCE, PRESIDENT,
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ASSOCIATION OF AMERICAN PORTLAND CEMENT MANUFACTURERS,
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THE ROAD MAKER,
DES MOINES, IA.

J. S. McCULLOUGH, CITY ENGINEER,
FOND DU LAC, WIS.

THOS. H. McDONALD,
STATE HIGHWAY ENGINEER,
AMES, IA.

JAMES R. MARKER,
STATE HIGHWAY COMMISSIONER,
COLUMBUS, OHIO.

J. P. MASON, PRESIDENT,
ILLINOIS STATE DAIRYMEN'S ASSOCIATION,
ELGIN, ILL.

JOHN C. SHAFFER, EDITOR,
CHICAGO EVENING POST,
CHICAGO.

JOHN D. SHOOP,
ASSISTANT SUPERINTENDENT OF SCHOOLS,
CHICAGO.

W. E. STALNAKER, PRESIDENT,
CHICAGO MOTOR CLUB,
CHICAGO.

GEO. F. SWAIN, PRESIDENT,
AMERICAN SOCIETY OF CIVIL ENGINEERS,
BOSTON, MASS.

A. N. TALBOT, PRESIDENT,
AMERICAN SOCIETY FOR TESTING MATERIALS,
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JESSE TAYLOR, EDITOR,
BETTER ROADS,
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N. E. TUNNICLIFF, CIVIL ENGINEER,
DAVENPORT, IOWA.

W. J. WARD, CHAIRMAN,
GOOD ROADS COMMITTEE,
INDIANA RURAL LETTER CARRIERS' ASSOCIATION,
CARMEL, IND.

CARL C. WIDENER, CITY ENGINEER,
BOZEMAN, MONT.

F. P. WILSON, CITY ENGINEER,
MASON CITY, IOWA.

Subsequently, the Advisory Committee elected W. F. M. Goss, Chairman, and J. P. Beck, Secretary. The organization of the Conference, the appointment of committees, and the preparation of the program, then proceeded under the direction of the Advisory Committee.

SUMMARY OF PROCEEDINGS

OF THE

NATIONAL CONFERENCE ON CONCRETE ROAD BUILDING

THE FIRST SESSION WAS HELD ON FEBRUARY 12, AT 2 P. M.

The meeting was called to order by Edward N. Hines, who moved the election of W. F. M. Goss as Chairman of the Conference, A. N. Johnson and Ira O. Baker as Vice-Chairmen and J. P. Beck as Secretary.

After the disposal of some minor business matters, the following resolution, introduced by S. E. Bradt, was adopted:

> WHEREAS, it is desirable in the discussions of this Conference to avoid all chance of the devotion of any considerable amount of the limited time to business discussions; and
>
> WHEREAS, it is desirable to devise an adequate means whereby consideration may be given to business questions of importance, motions and resolutions which may be introduced or suggested by the scientific discussions of the Conference; and
>
> WHEREAS, it may be desirable to preserve and publish the proceedings of the Conference, or portions thereof, or to give to the public a declaration of the opinions of this Conference as to the fundamental principles to be observed in road building of concrete; therefore, be it
>
> RESOLVED, that a Committee on Resolutions be appointed by the Chairman. Be it further
>
> RESOLVED, that all miscellaneous business, motions, resolutions, committee reports and discussions be referred to said Committee on Resolutions; and be it further
>
> RESOLVED, that said Committee on Resolutions be requested to present a report of its deliberations and recommendations, embracing a codification of the best practice in concrete road building.

The Chairman thereupon named the following to serve upon the Committee on Resolutions:

Richard L. Humphrey, Chairman;	Edward N. Hines,
Ira O. Baker, Secretary;	Sanford E. Thompson,
F. E. Turneaure,	W. K. Hatt,
A. Marston,	F. P. Wilson,
A. N. Johnson,	J. T. Voshell,
Thomas H. MacDonald,	C. W. Boynton,
James R. Marker,	Leonard S. Smith.

Upon motion offered by Charles P. Light, Dr. Goss was made ex-officio member of the Committee on Resolutions.

The Chairman then made the following statement:

Gentlemen, you will bear in mind that this Conference is not backed by any permanent organization and it does not, at this moment, at least, look forward to any permanent existence. It has no means of existence except such as may lie in the desire of the people to be together for the purpose of the discussions which are to occur here. There is one aspect, therefore, of the work of the Conference which we are incompetent to take care of and I am going to ask Mr. Hagar to speak to us concerning that. I take pleasure in introducing Edward M. Hagar.

Mr. Hagar:—Mr. Chairman and gentlemen: We are all confident that the papers that will be read at this Conference, as well as reports and discussions, will be very valuable and it will be desirable to have them published and distributed. As President of the Cement Products Exhibition Co., I therefore offer, on behalf of the Exhibition Co., to defray the expense of printing, publishing and distributing the proceedings of this Conference under the direction of the Resolutions Committee.

The Chairman:—I am sure that the Chairman voices the appreciation of the members of this Conference in saying to Mr. Hagar that we all greatly appreciate the courtesy of his interest and the generosity of his proposal.

If I may be permitted one moment in which to turn aside from the business considerations of this hour, I would not call your attention to the fact—for that would be unnecessary—but I would mention that this, the 12th day of February, is one of tender and precious associations. It will hardly be possible in our country today for people to gather for any purpose without thoughts of that great man whose life has distinguished and even hallowed the day. Helpful and inspiring thoughts they must be for any one who wishes even in the humblest way to work for his country, for her good name among nations, for the integrity of her government, for the welfare of her people. His life was spent for this and the spirit in which he conducted both small and great affairs is the spirit which ought to direct us in all of our considerations. It is significant that this meeting of ours begins its deliberations upon Lincoln's Birthday, and in recognition of the debt which we as citizens of this great nation and especially of this state of Illinois owe to Lincoln, I am going to ask that you all for one moment rise to your feet. (The audience arose.)

The following addresses were then given:

"The National Conference on Concrete Road Building"—W. F. M. Goss, Dean, College of Engineering, University of Illinois.

"Financing Permanent Roads"—S. E. Bradt, Secretary, Illinois State Highway Commission, Springfield, Ill.

"Can a Rural Community Afford Permanent Roads?"—Oliver H. Dunlap, President, Iowa State Supervisors Association, Kalona, Iowa.

"The Concrete Road System of Wayne County, Michigan"—Edward N. Hines, Chairman, Board of County Road Commissioners, Detroit, Mich.

SECOND SESSION OF CONFERENCE

HELD FEBRUARY 13, AT 10 A. M.,
VICE-CHAIRMAN A. N. JOHNSON, PRESIDING.

The reports of the following committees were received and discussed:

I—CONTRACTION AND EXPANSION OF CONCRETE ROADS

Chairman—R. J. Wig, Bureau of Standards, Department of Commerce, Washington, D. C.
N. H. Tunnicliff, Civil Engineer, Davenport, Iowa.
W. A. McIntyre, Engineer, Association of American Portland Cement Manufacturers, Philadelphia, Pa.

II—JOINTS FOR CONCRETE ROADS

Chairman—W. K. Hatt, Professor in Charge, School of Civil Engineering, Purdue University, LaFayette, Ind.
George W. Cooley, State Engineer, St. Paul, Minn.
R. J. Wig, Bureau of Standards, Department of Commerce, Washington, D. C.

III—AGGREGATES FOR CONCRETE ROADS

Chairman—Sanford E. Thompson, Consulting Engineer, Newton Highlands, Mass.
A. N. Talbot, President, American Society for Testing Materials, Urbana, Ill.
W. M. Kinney, Assistant Engineer, Universal Portland Cement Co., Pittsburgh, Pa.

IV—PREPARATION AND TREATMENT OF SUB-GRADE FOR CONCRETE ROADS

Chairman—Ira O. Baker, Professor of Civil Engineering, University of Illinois, Urbana, Ill.
A. R. Hirst, State Highway Engineer, Madison, Wis.
A. N. Johnson, State Highway Engineer, Springfield, Ill.

V—REINFORCEMENT OF CONCRETE ROADS

Chairman—Thomas H. MacDonald, State Highway Engineer, Ames, Iowa.
Henry E. Riggs, Professor of Civil Engineering, University of Michigan, Ann Arbor, Mich.
Richard L. Humphrey, President, American Concrete Institute, Philadelphia, Pa.

THIRD SESSION OF CONFERENCE

HELD FEBRUARY 13, AT 2 P. M.,
VICE-CHAIRMAN IRA O. BAKER, PRESIDING.

The following program was presented:
Address: "Experiments with Concrete for Roads Conducted by the United States Office of Public Roads"—J. T. Voshell, Senior Highway Engineer, United States Office of Public Roads, Washington, D. C.

VI—METHODS AND COST OF REPAIRING AND MAINTAINING CONCRETE ROADS

Chairman—Edward N. Hines, Chairman, Board of County Road Commissioners, Detroit, Mich.
J. C. McCullough, City Engineer, Fond du Lac, Wis.
F. P. Wilson, City Engineer, Mason City, Iowa.

VII—SHOULDERS FOR CONCRETE ROADS

Chairman—Walter Wilson Crosby, Baltimore, Md.
E. A. Kingsley, State Highway Engineer, Little Rock, Ark.
John H. Mullen, Secretary, Minnesota Roadmakers Association, St. Paul, Minn.

VIII—BITUMINOUS SURFACES FOR CONCRETE ROADS

Chairman—E. J. Mehren, Editor-in-Chief, Engineering Record, New York City.
Henry G. Shirley, Chief Engineer, State Roads Commission, Baltimore, Md.
James R. Marker, State Highway Commissioner, Columbus, Ohio.

IX—FINISHING AND CURING CONCRETE ROAD SURFACES

Chairman—F. E. Turneaure, Dean, College of Engineering, University of Wisconsin, Madison, Wis.
H. J. Kuelling, President, Wisconsin Highway Commissioners Association, Milwaukee, Wis.
E. D. Boyer, Engineer, The Atlas Portland Cement Co., New York City.

X—ECONOMIC METHODS OF HANDLING AND HAULING MATERIALS FOR CONCRETE ROADS

Chairman—Halbert P. Gillette, Editor-in-Chief, Engineering & Contracting, Chicago.
Donald D. Price, State Engineer, Lincoln, Neb.
Percy H. Wilson, Secretary, Association of American Portland Cement Manufacturers, Philadelphia, Pa.

At the close of this program a resolution was introduced by E. S. Larned, referring to the importance of conducting thorough investigations into the quality of the materials available in the various states for use in concrete, and calling upon the Governor and Legislature of the several states to consider the necessity for making appropriations to the proper agencies for conducting such investigations by the State Geologists, Universities, Engineering Experiment Stations and other proper agencies.

The resolution was referred to the Committee on Resolutions.

FOURTH AND FINAL SESSION OF CONFERENCE

Held February 14, at 10 A. M.,

Chairman Goss, Presiding.

The meeting gave its consideration to the following program:

Address: "Concrete Road Construction by the Ohio State Highway Department"—H. D. Bruning, Division Engineer, State Highway Department, Columbus, Ohio.

Reports of Committees:

XI—MIXING AND PLACING MATERIALS FOR CONCRETE ROADS

Chairman—Paul D. Sargent, Chief Engineer, State Highway Commission, Augusta, Me.
Arthur H. Blanchard, Professor of Highway Engineering, Columbia University, New York City.
C. W. Boynton, Inspecting Engineer, Universal Portland Cement Co., Chicago.

XII—COST OF CONSTRUCTING CONCRETE ROADS

Chairman—A. N. Johnson, State Highway Engineer, Springfield, Ill.
Joseph Hyde Pratt, State Engineer, Chapel Hill, N. C.
Albert Reichmann, President, Western Society of Engineers, Chicago.

XIII—THICKNESS, CROWN AND GRADES FOR CONCRETE ROADS

Chairman—Leonard S. Smith, in Charge of Roads and Pavements, University of Wisconsin, Madison, Wis.
Earle R. Whitmore, City Engineer, Port Huron, Mich.
T. R. Agg, Assistant Professor in Civil Engineering, Iowa State College, Ames, Iowa.

XIV—PROPORTION AND CONSISTENCY OF MATERIALS FOR CONCRETE ROADS

Chairman—C. U. Boley, City Engineer, Sheboygan, Wis.
C. C. Widener, City Engineer, Bozeman, Mont.
George A. Dingman, Engineer, Board of County Road Commissioners, Detroit, Mich.

XV—FORM OF SPECIFICATIONS FOR CONCRETE ROADS

Chairman—A. Marston, Dean and Director, Division of Engineering, Iowa State College, Ames, Iowa.
A. N. Talbot, President, American Society for Testing Materials, Urbana, Ill.
George W. Cooley, State Engineer, St. Paul, Minn.

REPORT OF COMMITTEE ON RESOLUTIONS

The following report of the Committee on Resolutions was then presented by its Chairman, Richard L. Humphrey, and unanimously adopted:

1—WHEREAS, the first National Conference on Concrete Road Building has proved an unqualified success, and

WHEREAS, the success of the Conference is largely due to the activity of its officers, the members of its Advisory Committee, and the Chairman and members of the special committees, therefore be it

RESOLVED, that this Conference expresses its hearty appreciation and thanks for the services rendered by its Chairman, W. F. M. Goss, by its Secretary, J. P. Beck, and by the members of its Advisory Committee for their labors in bringing about this successful Conference; and also to the Chairman and members of the various committees, and to its presiding officers, Ira O. Baker and A. N. Johnson, for the successful conduct of the sessions. Be it further

RESOLVED, that the thanks of this Conference be extended to those who presented addresses and took part in the discussions, and to those who by their participation in or presence at the deliberations contributed to its success.

2—WHEREAS, this Conference has been made possible through the invaluable assistance of the Cement Products Exhibition Co., and

WHEREAS, this Company has offered to defray the cost of printing the proceedings of the Conference, therefore be it

RESOLVED, that this Conference does hereby accept with heartiest appreciation and thanks, the offer of the Cement Products Exhibition Co.

3—WHEREAS, the Committee on Resolutions has been charged with the preparation of a declaration of the opinions of this Conference as to the fundamentals to be observed in concrete road building, therefore be it

RESOLVED, that the Committee on Resolutions be requested to continue its work of editing and arranging the papers, addresses, reports and discussions coming before the Conference, and that its duties cease with the completion of this work.

4—WHEREAS, many matters have come before this Conference for consideration upon which further investigation and study is necessary, and

WHEREAS, many of its Committees have been unable to present more than preliminary reports, and

WHEREAS, the large attendance and deep interest manifested in the meetings of the Conference emphasize the need for such deliberations, and

WHEREAS, the Cement Products Exhibition Co. has offered to provide funds to defray the expense of another Conference and for publishing the results of its deliberations, therefore be it

RESOLVED, that it is the sense of the Conference that its Advisory Committee should continue with power to determine whether or not another Conference upon this subject is desirable, and to fix the time and place of meeting. Be it

RESOLVED, that it is the sense of this Conference that if such a future Conference be held it should be at the time and place of the Annual Convention of the American Concrete Institute. Be it

RESOLVED, that the Advisory Committee shall have full power to make all necessary arrangements for such a future Conference, and to increase its membership and the number of its officers, and if necessary to create an Executive Committee.

5—WHEREAS, concrete is a building material of great value in the economical construction of highways, buildings, bridges and other structures, and

WHEREAS, its rapidly increasing use is of great importance in the permanent developments in each state, and

WHEREAS, the quality of the sand, gravel and stone available for use in concrete in the various localities in each state is of fundamental importance and has not yet been extensively determined; therefore, be it

RESOLVED, by the National Conference on Concrete Road Building, assembled in Chicago, February 12, 13, 14, 1914, that it is highly desirable that the materials available in the various states for use in concrete should be examined and tested as rapidly as possible by competent State Geologists, Universities, or Engineering Experiment Stations, and be it further

RESOLVED, that the Governor and the Legislature of the several states be provided with a copy of these resolutions and asked to seriously consider the great necessity for making adequate provision and appropriation to the proper agency for the prompt inauguration of such investigations.

6—Your Committee has devoted much time and held frequent meetings and has endeavored to crystallize the thoughts and recommendations presented in the several reports and developed in the discussions thereon, and appends herewith the results of its deliberations in the form of recommended practice for the construction of concrete roads, and recommends that same be adopted as the opinion of this Conference.*

*Refer to next page for Recommended Practice.

RECOMMENDED PRACTICE

The National Conference on Concrete Road Building adopts the following principles as representing good practice in the construction of concrete roads.

BRIEF SUMMARY OF FUNDAMENTAL PRINCIPLES

The salient features of the recommended practice are:

1. The aggregates should be clean and hard.

2. The sand should be coarse and well graded.

3. A rich mixture should be used.

4. The materials should be correctly proportioned.

5. The materials should be thoroughly mixed.

6. The inspection should be intelligent and thorough.

7. When in doubt, reinforce the pavement.

8. The sub-grade should be of uniform density, thoroughly compacted and drenched with water immediately before placing concrete.

9. The concrete should be of a viscous, plastic consistency.

10. After placing, the concrete should be immediately covered and kept moist and not opened to traffic for four weeks.

DETAILS OF RECOMMENDED PRACTICE

The details of recommended practice are as follows:

1. GRADING

(a) SLOPES AND GRADES: The grade of the roadway and the side slopes should be determined by an engineer to meet the local conditions.

(b) EXCAVATION OR TREATMENT OF EXISTING ROADWAY: The fundamental requirement of the sub-grade is that it should at all times be of uniform density, so that it will not settle unevenly and cause cracks in the surface of the pavement, and no part of the work is more worthy of intelligent care and painstaking labor than the preparation of the sub-grade; the slight additional cost necessary to insure good results is abundantly justifiable. When the pavement is constructed on virgin soil, care should be taken to remove all soft spots so as to insure a uniform density; and if constructed on an old roadbed, even greater care must be taken in preparing the sub-grade, which is likely to be more compact in the center than at the sides, and consequently there is more danger that the pavement will settle unevenly, causing cracks.

(c) FILLS: Where roadways are constructed over fills, extreme care should be observed to insure the use of proper material in layers of such thickness that they may be thoroughly compacted so that when the fill is completed there will be a minimum of settlement. The fill should be allowed to stand for as long a time as possible so that it will have an opportunity to settle thoroughly before the pavement is placed thereon. In general,

the material composing a fill should be deposited in layers not more than one (1) foot in thickness and each layer should be thoroughly wetted and compacted with a roller weighing ten (10) tons.

(d) SUB-GRADE: Before the pavement is laid, care should be taken to bring the sub-grade to proper elevation and to see that it is thoroughly compacted; any soft spots or settlements should be filled with a suitable material.

2. DRAINAGE

The drainage of the roadbed of a pavement is of vital importance. If the sub-grade is not well drained, there is danger of unequal settlement after the pavement is laid, causing longitudinal cracks; there is also a possibility that the frost may lift the edges of the pavement and likewise produce cracks. The character of drainage necessary will depend on local conditions. It is recommended that, in general, proper drainage may be secured through lateral ditches. If underground water is present this may be removed through the use of drain tile laid at a suitable depth on either side of the roadway, or on one side with cross drains from the other side. The top of the tile should not be less than three (3) feet below the sub-grade.

3. MATERIALS

(a) PORTLAND CEMENT: The Portland cement should meet the requirements of the Standard Specifications for Portland Cement of the American Society for Testing Materials.

(b) AGGREGATES: The Conference is of the opinion that naturally mixed aggregates should not be used without screening and remixing in proper proportions. The quality of the aggregates can usually be materially improved by washing. Aggregates should not contain frost or frozen lumps.

(A) FINE AGGREGATE: Fine aggregate should consist of sand, crushed stone or gravel screenings, graded from fine to coarse and passing when dry a screen of one-quarter inch mesh. It should be preferably of silicious material, hard* and durable, clean, free from dust, loam, vegetable or other deleterious matter.

In first-class sands, properly graded from fine to coarse, not more than fifteen (15) per cent of the grains will pass a sieve having fifty (50) meshes to the linear inch and not more than two (2) per cent will pass a sieve having one hundred meshes to the linear inch. Fine aggregate should be of such quality that mortar composed of one (1) part Portland cement and three (3) parts fine aggregate, by weight, when made into briquettes, will show a tensile strength at least equal to the strength of a 1:3 mortar of the same normal consistency made with the same cement and standard Ottawa sand.

Since it is impossible to determine the quality of sand by the usual eye and hand examination, the Conference is of the opinion that their quality should be determined by tests for tensile strength and mechanical analysis.

(B) COARSE AGGREGATE: Coarse aggregate should consist of clean, hard** and durable crushed stone or gravel graded in size, all of which

*No material is suitable which is not approximately as hard as flint or quartz. The Conference recommends that an investigation be made to devise a suitable, simple test for hardness.

**The term "hard" as used here refers to the French co-efficient of wear; the Conference recommends that the material should have a co-efficient of not less than twelve. For method of determining French co-efficient of wear, see Baker's Roads and Pavements, page 184, Edition of 1913.

will pass a one and one-half ($1\frac{1}{2}$) and be retained on a one-quarter ($\frac{1}{4}$) inch screen.

It should be clean, hard and durable and free from all deleterious matter, and should not contain flat or elongated particles.

(c) WATER: Water should be clean, free from oil, acid, alkali or vegetable matter.

(d) REINFORCEMENT: All reinforcement shall develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180° around one diameter and straighten without fracture.

All reinforcement should be free from excessive rust, scale, paint or coatings of any character which would tend to reduce or destroy the bond.

4. FORMS

(a) MATERIALS: Forms may be of wood or metal and should be free from warp, of sufficient strength to resist springing out of shape, and have a width equal to the required thickness of the pavement.

(b) SETTING: The forms should be well staked and rigidly held in position and their upper edges should conform to the established grades of the pavement. The Conference believes that metal forms are preferable. Where wooden forms are used they should be capped with metal. The forms should be thoroughly cleaned before being used.

5. THICKNESS

The thickness of the concrete pavement is controlled by many factors such as condition and character of the sub-grade, drainage, traffic, climatic conditions, width of pavement, etc. Three distinct types of cross sections are in general use:

1. Uniform thickness of concrete for all widths of roadway and consequently the same amount of crown in the foundation as in the surface.
2. Roadways in which the concrete is thicker at the center than at the edge, but in which some crown is given to the foundation.
3. Concrete roadways in which the concrete is thicker at the middle than at the edge, but which are built upon a flat sub-grade.

The Conference recommends the latter type for all roadways of twenty (20) feet or less in width.

6. WIDTH

The Conference recommends that the minimum width be ten (10) feet for single track roads and eighteen (18) feet for double track roads. For roads eighteen (18) feet or more in width, it is unnecessary to provide turnouts of gravel or macadam shoulders, which greatly increase the cost of maintenance.

7. CROWN

Unlike some types, concrete pavements are not damaged by water. If it were not for the need for drainage, a perfectly flat road would be preferable because it would lead to a better distribution of the traffic. Since thin sheets of water or ice on the surface of any pavement are objectionable, a slight crown should be provided to insure drainage of the surface, and the Confer-

ence is of the opinion that for country highways a crown of one one-hundredth (1/100) of the width is sufficient. Because of the peculiar needs for drainage in cities, a crown of one-seventieth (1/70) of the pavement width will usually be found ample. On steep grades this crown may be correspondingly reduced.

8. JOINTS

(a) WIDTH AND LOCATION: It is a well known fact that under ordinary conditions cracks may be expected in plain concrete unless joints are provided at intervals, but such cracks may be prevented or so distributed as to become small and unobjectionable, through the use of sufficient reinforcing steel. Joints are a source of trouble, even if properly spaced and properly constructed and, if possible, should be avoided. These joints necessarily interrupt the continuity of the pavement and are a source of expense in maintenance.

The Conference is of the opinion that where joints are used they should be located at intervals of from 25 to 50 feet, although under favorable conditions longer sections have been successfully used.

While it is the current practice to provide metal protection for the joints, the Conference is of the opinion that later experience may show that a single layer of prepared felt not exceeding one-eighth (⅛) of an inch in thickness without metal protection will prove more satisfactory.

(b) PROTECTION AND FILLER: The joint is preferably protected by two pieces of metal, having high resistance to abrasion, three (3) inches wide and about three-sixteenths (3/16) thick, between which is placed one layer of prepared felt of a width equal to the thickness of the pavement.

9. REINFORCING

The Conference is of the opinion that all roads exceeding twenty (20) feet in width should preferably be reinforced with some form of metal fabric and recommends that the cross-sectional area of the reinforcing metal running parallel to the center line of the pavement should be about 0.038 square inch per foot of pavement width and of metal running transversely 0.049 square inch per foot of pavement length, the purpose of such reinforcing being to distribute the effect of expansion and contraction due to temperature changes and moisture content of the concrete, as well as the weight of traffic over defects in the sub-grade. The reinforcement should be embedded at least two (2) inches and not more than three (3) inches below the surface of the pavement.

10. MIXING AND PLACING CONCRETE

(a) MEASURING: The method of measuring materials for the concrete, including the water, should be one which will insure correct proportions of each of the ingredients at all times. It is recommended that a sack of Portland cement, containing ninety-four (94) pounds net, be considered the equivalent of one cubic foot.

(b) PROPORTIONS: The Conference recommends that the proportions do not exceed five (5) parts of fine and coarse aggregate to one (1) part of Portland cement, and that the fine aggregate should not exceed forty (40) per cent of the mixture of fine and coarse aggregates.

(c) MIXING: Ingredients of which the concrete is composed should be mixed in a batch mixer of approved type, and the mixing should be con-

tinued after all the materials are in the mixer for at least one minute; during the mixing time there should be at least fourteen (14) complete revolutions of the mixer. The Conference is decidedly of the opinion that the durability of a concrete road is largely affected by the proper proportioning and thorough mixing of the ingredients.

(d) CONSISTENCY: The practice is to mix concrete entirely too wet. The consistency should be such as not to require tamping, but not so wet as to cause the separation of the mortar from the aggregate in handling and placing. The concrete, when properly mixed, should have a viscous, plastic consistency.

(e) PLACING: Just before placing the concrete the sub-grade should be brought to its original surface, if it has been disturbed by teaming or other causes, and thoroughly saturated with water. The concrete should be deposited rapidly in successive batches to the required depth and width of the pavement, in a continuous operation. The section should be completed to a transverse joint, without the use of intermediate forms or bulkheads, or a transverse joint may be placed at the point of stopping of the work. In case the mixer breaks down the concrete should be mixed by hand to complete the section.

(f) FINISHING: The surface of the concrete should be struck off by means of a template moved with a combined longitudinal and transverse motion. The excess of material accumulated in front of the template should be uniformly distributed over the surface of the pavement except near the transverse joint, when the excess material should be removed.

The concrete adjoining the transverse joint shall be dense and any depressions in the surface shall be filled with a mortar composed of one (1) part of Portland cement or not more than two (2) parts of fine aggregate. After being brought to the established grade with a template the concrete should be finished, from a suitable bridge, with a wood float to true surface. A metal template should not be used.

(g) RETEMPERING: Retempering of mortar or concrete which has partially hardened, that is, mixing with additional materials or water, is strongly condemned and should not be permitted.

(h) TEMPERATURE BELOW 35° FAHR.: If the temperature during the progress of the work should drop at any time below thirty-five (35) degrees Fahrenheit, the water and aggregates should be heated and precaution should be taken to protect the work from freezing for a period of at least ten (10) days. In no case should concrete be deposited when the sub-grade is frozen.

The Conference is of the opinion that under no condition should concrete road construction be carried on during freezing weather.

11. CURING AND PROTECTING

The curing of the exposed surface of concrete is a matter of the greatest importance. Good concrete can be easily destroyed by too rapid drying out or opening it to traffic at too early a period. It is, therefore, highly desirable that the finished pavement should be covered with sand or earth and kept sprinkled for a period of at least fourteen (14) days, the purpose of which being to keep the concrete moist, and to prevent the evaporation of the water

which is necessary for the proper hardening of the concrete. Where conditions will permit the Conference would recommend that the concrete pavement be not opened to traffic until after an interval of at least four (4) weeks, during which period it shall be protected as above described.

12. SPECIFICATIONS

Since no specifications were considered by the Conference the Standard Specifications for Pavements and Roadways of the American Concrete Institute are recommended.*

Respectfully submitted,

COMMITTEE ON RESOLUTIONS.

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*See pages 181 to 204 inclusive.

THE NATIONAL CONFERENCE ON CONCRETE ROAD BUILDING

ADDRESS BY W. F. M. GOSS, DEAN COLLEGE OF ENGINEERING, UNIVERSITY OF ILLINOIS, URBANA, ILL., CHAIRMAN OF CONFERENCE

On behalf of your Advisory Committee, and of those officers of the Committee who have been so diligent and successful in making preparations for our gathering, I extend to you, the delegates to this, the National Conference on Concrete Road Building, a most hearty welcome.

Those who introduce a movement are often led by a certain inspiration which begets confidence in the public, which reaches a speedy and satisfactory conclusion, and which is far-seeing enough to plan intelligently for future ages as well as for their own. I believe the movement in which we are now specially interested has been thus inaugurated, for I predict that this National Conference, assembled for the purpose of discussing the principles which should control in the design and construction of a new type of roadway, will exert influence upon every part of our country and will ultimately confer benefits upon all classes of people.

It is significant, both in its relation to this day and to the purposes of this conference, that a proclamation has been issued by the Director of the Lincoln Highway Association declaring its purpose to secure the construction, as a dignified, a useful and a lasting memorial to the nation's great benefactor, of a Lincoln transcontinental highway, to be built in concrete.

The problem of road construction in the United States, as it confronts society at this time, is a great issue. Those who desire immediate benefits and who fail to interpret the present situation in terms of past conditions, are inclined to contrast the imperfections in the highways of our own country with the superior qualities of those of England and Continental Europe. They may even conclude that some one is to blame for our lack of progress, but basing judgment upon a large view of the situation we are not justified in entertaining any such feeling. The good roads of the old world have been built by people who live under settled conditions, or they have been developed in response to the exigencies of war. We, in this country, have only in recent years become well established in the occupancy of our territory, and the process of gaining possession of our lands has made us busy with other things. Only now are we ready to consider the means of bringing our roads to a standard which will satisfy the requirements of a modern settled community. An era of great progress is just before us. The farmer is no longer content to plod in the road; he wants a road upon which he can travel rapidly and comfortably. The man of affairs finds that business flows in stronger streams where roads are good. Cities are discovering that trade and municipal prosperity are stimulated by good roads, and railroad and navigation companies are finding that in the development of their traffic good roads serve as effective feeders. People everywhere are coming to understand that it is expensive to move loads over poor roads, and that the extra cost to the farmer resulting from their low efficiency is a tax upon the community.

Meanwhile, the severity of the service to which the modern highway is subjected has increased enormously. The good road of a decade ago is no longer sufficient to withstand the traffic of the present day. Travel for pleasure to a considerable degree has deserted the steam railway and taken to the country highway. The horse is giving way to the motor; the light vehicle is being superseded by heavy trucks, and the speed with which all traffic moves is increasing. The public appreciation of these facts is undergoing rapid development. No one who reads or travels can question the imminence of great undertakings in the development of good roads in these United States; and, since the enterprise has been so long in abeyance the rate of progress, once a real start is made, is bound to be rapid. The importance of securing a correct and otherwise satisfactory basis upon which to make the expenditures which are in prospect, is not likely to be overestimated. Rarely has the scientist, the engineer and the public official had such an opportunity for service as that which now confronts them in the necessity for solving the road-construction problems of the immediate future.

There is available to the present-day road-builder a wide range of choice in the selection of materials. One of these materials is concrete. In concentrating our attention upon this one material, it is not our purpose to disparage the value of any others which may properly be employed in highway construction, nor to deprecate the application of any principle of design which may properly be used in roadway construction, nor to slight or to pass judgment upon the opinion or the work of the advocate of any system of road-construction which has proved itself, or is in the process of proving itself, serviceable in the upbuilding of better roads. The attitude of the Conference is one of friendliness to all good and honest work in the promotion of the general cause. But its peculiar purpose is that of considering the possibilities of concrete as a material for road-construction, and our consultations are to be for the purpose of bringing to light not only the merits of the concrete road, but the demerits as well, developing methods for their possible elimination. We are to devote four formal sessions to a discussion of this single type of road-construction. We are to have presented here by those best qualified to speak, a description of the best methods of procedure in the building of such roads; we are to be told what are the really important things to be given attention in the process; we are to consider what should be the nature of specifications governing the construction of such roads; we are to have presented such information as may be available concerning the behavior of the concrete road under exposure to the weather, under the burden of traffic, and in resisting wear; we are to discuss methods to be employed in maintenance, and so far as we may be able, we are to define all the details of a new practice for the guidance of all interested. In so far as the deliberations of this Conference shall result in the establishment of facts concerning these and related matters, its work will aid in supplying a basis for correct opinions concerning the future usefulness of concrete as a material for highway construction.

It is the part of your Chairman to introduce to you those whose work qualifies them to speak concerning the highly technical aspects of our general problem and especially to see that ample opportunity is granted for the presentation of reports of committees in the preparation of which many distinguished persons have given unsparingly of their time.

FINANCING PERMANENT ROADS

Address by S. E. Bradt, Secretary, Illinois State Highway Commission, Springfield, Ill.

So far as I have been able to discover there is no royal road to the fortune that will be necessary to construct an adequate system of permanent highways.

There is only one source—and that source is the people. There are, however, several channels of taxation touching this source at different points, reaching different classes of people, different classes of wealth and different localities.

These channels are: the federal government, deriving its income mainly through customs and internal revenue, thus drawing indirectly from special classes; the state tax, reaching all property within the state and including all the large cities and corporations, as well as many fees and special taxes; the county and township taxes, more localized in their scope and nearer the source of the benefits, and in addition to the above the automobile and kindred license fees, collected from a certain part of those benefited.

By utilizing all of the above channels practically all of the people benefited will bear a part of the expense. Furthermore, the magnitude of the undertaking demands that they should all be utilized in order that the necessary amount of money may be made available without the tax being burdensome to any one class or group of people.

There is much discussion both in congress and out as to what part the federal government should take in the improvement of our highways. The government has nearly completed one of the most stupendous undertakings of modern times at a cost of from $300,000,000 to $350,000,000; an undertaking not only national but international in its scope. The greater part of the expense of this work has been paid from current revenues.

The government from its foundation has recognized the principle of aiding and fostering internal improvements, and many millions of dollars are expended annually for public buildings, improving rivers and harbors, and other similar undertakings.

We must admit, however, that the improvement of our highways is more important and of vastly greater benefit to our people than any of the other work to which I have called attention.

The reason given by legislators for not having already undertaken to assist in this movement is the vast amount of money required; claiming that they dare not commit the government to such a stupendous project. Some additional excuse for this backwardness is found in the fact that traffic conditions are demanding an entire change in road construction, and in the further fact that the advocates of good roads have not been able to agree upon a standard of construction, the method by which the government should enter into the project or the amount of money to which it should be committed.

That the people are demanding action from congress is apparent from the different measures recently introduced calling for appropriations for this work. Many of the bills introduced have failed to pass, because they have asked the government to build certain local and specific highways benefiting

a comparatively small number of people. It is conceded that federal aid should be upon a basis broad enough to reach every state in the union and should be given only under such restrictions as would guarantee that the money would not be spent for temporary work, but would be employed in such construction as would endure. The people of the country are only waiting for a reasonable measure of assistance, and if the federal government will speedily develop a definite plan for such assistance it will give the needed impetus to start the work in all sections of the country.

The government will soon reach the end of its expenditure for the Panama Canal. It seems entirely appropriate that this fund together with such other money as can be spared from internal improvements, equaling at least $50,000,000 a year for a period of 15 years, should be diverted to road work.

If the government shall undertake to assist in this work either through building and maintaining certain national highways connecting county seats and large cities, or shall allot to each state a proportionate sum to assist the state in constructing a system of main market roads or post roads, the burden which would fall upon the state, county and township would be greatly lessened and the work could proceed at a much more rapid rate. It has been very properly suggested and approved by all of our National Road Organizations that congress authorize the president to appoint a commission to carefully investigate the subject and recommend to congress how and to what extent it shall enter into this work.

In many of the states a system of main roads varying from 10 to 20 per cent of the whole has been laid out to be improved either by the state or at the joint expense of the state and the county, leaving the remainder of the roads under the control of the township authorities. This appears to be an equitable distribution of the cost and in the end will insure the improvement of the main market roads, inter-county and through routes. The problem, however, is to provide funds in sufficient amounts to enable the work to progress as rapidly as the people demand the improvement.

I have said in the beginning that in order to construct an adequate system of roads we must utilize all channels of taxation. Not only that, but if we are to construct this system of main roads within a comparatively short period of time the tax instead of falling upon the present generation should be spread over a period of years approximately equivalent to the life of the improvement. This can be done only through a bond issue. In the issuance of bonds for public improvement not only should the maturity of the bonds fall within the life of the improvement, but the maturities should be so arranged that the taxpayers would get value received each year for the amount of bonds retired during that year; thus requiring a serial bond.

If put upon this basis, it is evident that a bond issue is the most equitable method of financing road construction, as it would be manifestly unfair to the present taxpayers, if able to do so, to pay the entire cost of an improvement that will last for 15, 20 or more years, and that will be used to greater extent by the coming generations than by themselves. The principle of giving value received to all of the taxpayers who assist in paying the bonds has been frequently disregarded by states and municipalities, not from a desire to impose a burden upon those who pay the cost, but from the lack of correct information as to the durability of the work for which the bonds were issued. This has been to some extent excusable in the matter of bonds for road construction, because of the changing traffic conditions which could not be foreseen.

I believe, however, that we are today in position to judge sufficiently of traffic requirements of the next 15 or 20 years to build our roads to meet these requirements.

Another important feature in considering the equity of a bond issue for road improvement is that the saving indicated by the comparative cost of hauling in the United States and European countries would be sufficient to pay not only the interest, but also the greater part of the principal within a period of 15 or 20 years.

It is customary to issue bonds for school buildings, sewers, for water works, for lighting systems and other public improvements. All of these are essential, but none are more fundamental than good roads. Good roads logically precede all of them. Transportation, upon which distribution depends and of which highways are the undeveloped part, follows p oduction and naturally precedes better sanitary conditions and education. This relation has not been generally recognized up to the present time, but as demand overtakes supply, and the cost of living becomes a more acute factor, the economic advantage of good roads will assume its proper place.

Another feature that should be given careful consideration in connection with financing road improvement is the more economical expenditure of the funds that we are raising today for road purposes.

The Office of Public Roads at Washington estimates that we are raising at the present time for road and bridge purposes approximately $180,000,000 annually. In 20 years at this rate we would have raised $3,600,000,000, a sum large enough if expended systematically by competent road builders to give us 300,000 to 350,000 miles of permanent roads, which with the present improved mileage would accommodate 90 per cent of the traffic. We are raising in the State of Illinois $7,000,000 annually. In 20 years this means $140,000,000, enough to improve 15,000 miles of our main market roads and give us with our present improved roads from 20 to 25 per cent of our mileage. A considerable part of these large amounts must be used for bridges and culverts and the care of the earth roads, a part is now being used for durable road work such as we are advocating, and a very much larger part could be used for that purpose if we were working under a proper system. Many of the states are using the township system, similar to that in operation in Illinois. I therefore shall illustrate my point by our system.

The $7,000,000 expended in Illinois is raised through a township tax by the 1,600 townships in the state and would thus average about $4,500 per township. Each township is divided into three road districts and elects a highway commissioner for each district, who has the expenditure of his share of the road money, averaging $1,500, entirely independent of any other official. It must be understood that in many cases the amount available is much below the average of $1,500, while in other cases it is considerably more, but generally speaking it is not large enough to encourage the highway commissioner in laying out any plan for his work, or in attempting to do any work of a permanent character. This results in the money being expended in the temporary patching of bad roads, bridges and culverts that bring no lasting benefit. What railroad having $7,000,000 to expend in construction and maintenance would divide it among its section foremen, and permit each foreman to build and maintain his particular section as he saw fit regardless of any advice from the chief engineer, or regardless of what the other section men were doing? What would be the results as to efficiency and economy of such a policy? And yet that is similar to the system of highway management under which many states are operating.

The question is, how can we correct this situation and conserve this money for permanent work? My suggestion is that if we made the county the *unit for road taxation and control of road funds*, and put the care of the roads and bridges as well as their improvement under a county board of three members, one of whom should have had some technical knowledge of road construction and all of whom would give their time to the work, at the same time relying upon the State Highway Department for assistance and advice, that we could place our road building upon a practical basis. This system would produce a marked saving in all lines of expenditure.

I will cite one instance. Under the present system many townships own very little, if any, machinery and therefore are greatly handicapped in doing their road work, while on the other hand many townships have purchased a large amount of machinery, some of it practical and some of it useless. In one county in Illinois, containing 28 townships, 14 of the townships have each purchased a tractor and a large road grader at an expense of about $4,000 for each outfit. Some of the other townships in this county do not want to be left behind and are seriously considering the purchase of similar outfits. These tractors and graders are for grading the earth roads and, while excellent outfits for that purpose, will not be used by any township to exceed 20 days in any one year. Supposing the county had charge of this work, two or three of these $4,000 outfits would do the work of the entire county and every township would get the benefit, thus resulting in a saving to the county of at least $40,000. Furthermore, under the county unit plan every county could own in addition to the necessary small tools one or two steam rollers as well as a train of dump wagons to be drawn by a tractor for the construction and repair of roads. The machinery necessary for economical road work could be owned by a county at much less than the townships are now expending for incomplete and inefficient outfits. It should be said that in this state under the new road law we are not only tending toward the county unit plan through the State Aid Section of the law, but are providing for a county superintendent of highways whose duty it is to advise and assist the township highway commissioners as well as to approve all construction in excess of $200 and supervise the work for which the money is expended.

There is still remaining to consider one channel of taxation, namely, the automobile and kindred license fees. This special tax is levied because of the excessive damage to the roads by the motor driven vehicles. These fees should therefore naturally go to the maintenance fund and if we shall construct the more permanent type of road such as brick or concrete, these fees will undoubtedly furnish an ample maintenance fund for years to come. The amount of the license fee to which motor vehicles are subjected varies considerably in the different states and could undoubtedly be increased in some of the states where the smaller fees are being charged. The owners of these vehicles should be very willing to pay increased fees where the money is being properly expended either for more permanent road construction or proper maintenance.

As showing what can be done within a comparatively short period of time towards permanent road improvement by a judicious combination of direct tax by the state and county, together with the issuing of bonds for one-half the cost of the improvement, let us take the State of Illinois as an illustration.

I have stated heretofore that Illinois is spending $7,000,000 annually. Assuming that it will require $2,500,000 annually to take care of the bridge and culvert expense and that it will also require $1,500,000 annually to grade and drag the earth roads properly, which will allow about $20 per mile

per year, we would still have left a total of $3,000,000 which can be properly applied to more permanent road construction. I have also stated heretofore that $7,000,000 per year over a period of 20 years would complete our system of state aid roads. This would mean that for the next 20 years we would be obliged to raise through state and county taxes $4,000,000 per year in addition to the $3,000,000 which can be saved from our present taxation.

Assuming that the average equalized assessed valuation for the state for the next 20 years will amount to $3,000,000,000, the $4,000,000, above referred to, would cost the taxpayer an average of 13 cents per $100 of assessed valuation. This would mean to the man owning a home valued at $1,500, assessed at $500, an additional tax of 65 cents per year; to the farmer of the state owning the average sized farm of 129 acres, assessed at $20 per acre, an additional tax of $3.35 per annum, or less than 3 cents per acre.

The people, however, are not willing to wait 20 years for this system of improved roads. Assuming that it will take at least 10 years to do the construction work, we would then require a fund of $14,000,000 a year, $7,000,000 of which would be provided by direct tax as heretofore indicated and $7,000,000 thru a bond issue. This $7,000,000 in 10-year bonds would be issued each year, one-half by the state and one-half by the county, for the first 10 years and mature serially over the last 10 years, and each issue would mature in 10 years from the time of the construction of the particular section of road for which it was issued. You will understand that the fund for paying the principal of the bonds is provided through the annual $7,000,000 tax. The only difference in expense therefore between taking the entire 20 years to do the work and doing the work in 10 years will be the interest on the bonds. This will average $1,400,000 per year for the entire 20 years and will add 5 cents per $100 of assessed valuation to the taxes. Thus it will cost the man owning the $1,500 home 25 cents per year more if we shall build this system of roads in 10 years instead of 20 years, and the farmer owning the average sized farm $1.29 per year more, or 1 cent per acre.

The above estimates are made on the supposition that the state and county assume the entire burden of constructing this system of main roads. If the federal government should (and we believe it will) assume a part of this burden either through building a system of national highways connecting the larger cities and capitals of the states, or shall allot to the different states certain sums to assist in constructing the main market and post roads, then this estimated local cost would be materially reduced.

I wish to say in conclusion that if we can unite the federal government, the state, the county and the township in this enterprise under a conservative and carefully worked-out plan, we can finance the improvement of our main roads within a reasonable period of time without inflicting any great burden upon the people. In many sections of the country the people are demanding that this work shall begin without further delay and be carried on to an extent that will give promise of its early accomplishment. They want the roads now while they are here to use them and if the present leaders do not provide the plan and the means by which the roads can be constructed, the people will provide other leadership that will give them what they demand.

CAN A RURAL COMMUNITY AFFORD PERMANENT ROADS?

ESS BY OLIVER H. DUNLAP, PRESIDENT, IOWA STATE SUPERVISORS ASSOCIATION, KALONA, IOWA

CHAIRMAN: GENTLEMEN OF THE CONFERENCE:

is with some degree of pleasure and a good deal of regret that I stand you at this time to talk on the subject of permanent roads. It ought a pleasure to any man to be accorded the privilege of meeting with a of men of this kind with so great a cause at heart as that of permanent I regret, gentlemen, I extremely regret that I have not the brain of esman or the tongue of an orator that I might express myself more as I would like to do at this time, and I assure you, gentlemen, it was some hesitancy that I accepted this invitation, realizing as I do that I not only before the educated but the educators of the land, and realiz- so that the only store of knowledge that I have to draw from is that erience which I have gathered along life's pathway. And I come to not as one who claims to know everything from the second year of on down to the present time on road building, but as a man from a district in the state of Iowa, and I will try to tell you something of the ions as I see them there.

ne subject assigned to me is, "Can a Rural District Afford to Build unent Roads?" And right here I want to find just a little fault with program committee. They gave me just a little too much territory and t to state here that my remarks will deal primarily with Iowa, for I little or nothing of the conditions in other states.

ow, I am going to answer this question just as I believe nine out of the farmers of Iowa would answer. I am going to say no, and then y version of the situation and say, not now. Now, I expect that answer rate a little on the ears of some of you, coming from one who claims a good roads enthusiast and believing that we are fast approaching the nent road age, and I imagine now that some of you are asking: "Why ow?" And the best answer that I can give to that is—"Because we never begun."

or fifty years we have been working the roads of Iowa without any n. We commenced no place and stopped nowhere. We had no end im in view. We had no law fixing the width or elevation of grade. ad every conceivable type or style of bridge. We had township and y bridges, but no one knew where the township bridge stopped, or the y bridge began, and the only wonder, as we stand and look over the s that we have accomplished as much as we have.

'e therefore have much to do before we can start in a practical way to permanent roads. One of the first and most essential things is per- nt culverts and bridges. Second, the establishing of maximum grades, is going to take both time and money. Surface and sub-drainage must sidered. And another important thing to my mind is a getting together material men and road-building officials, so a specific price for a ngth of time can be established. This sliding scale that we have ect to in the buying of cement must be eliminated, and last, but not

least, we must have time to get a trained corps of road builders, which we are very short of at the present time. Another thing to be considered is that word "permanent." What is a permanent road? When our new road law was in the making, every conceivable type of road was suggested, and each was referred to as a permanent road until, finally, the word permanent did not mean anything when used in connection with the word road.

But we have many encouraging signs, gentlemen. We have many factors that are working separately, selfishly and yet, collectively, they are all working for better roads. I suppose the greatest factor we have is the new road law that went into effect last April, and while that road law was a sore disappointment to the hard roads boosters, yet, gentlemen, to my mind, it is one of the very best laws that we could have at the present time. The framers of that law had a wider vision than most of the hard roads boosters. It conceived the idea that, before we began to build permanent roads for the few, we must build good dirt roads for the many, and so it set about to take the principal trade roads of each county and make them the very best dirt roads that can be made. It provided for the cutting of hills and filling of vales, the establishing of grades, proper drainage and permanent culverts and bridges. And, while it is true that the word permanent is not used in connection with dirt roads in this law, the practical road builder can see not only the very best dirt road, but he can see, in every bridge built, every culvert put in, in every scraper of dirt moved, the essential foundation and the definite end in view—that of a permanent hard road.

Another factor is the army of good roads boosters that make up the road organizations of the state. These associations are well organized; they have their meetings; there is quite a rivalry—a sort of selfish pride—as to which will be the best road, but, as a whole, they are all working for the one end—a permanent road.

The mail carriers of the state, with an army of 2,500 men that travel practically every mile of the main roads every day, are all boosters for better roads.

The educators of the state, that are clamoring for the consolidation of schools, so that the farmer's boy may have an equal chance with his town cousin, tell us that the greatest obstacle is the condition of our roads, and they are asking for a 365-day road.

And so I might go on enumerating the many factors all trending in the one direction, which must sooner or later come—the period of permanent roads.

Another thing that is encouraging is the great strides we have been making in the past. When we look back over the past, we see that the luxuries of only a few years ago are absolute necessities today. Twenty-five years ago if you had asked me, "Will farmers ever have a daily mail?" I would have answered "No." And yet, today, they not only have their daily mail brought to their doors, but groceries and dry goods as well. Twenty years ago if you had asked me, "Can the farmer ever own and maintain a telephone system?" again I would have said "No"; but today we find practically every farmer has a 'phone in his house. And, coming down a little nearer, if ten years ago you had asked me, "Will the farmer ever be able to own and use an automobile?" again I would have answered "No," and added, "None but the wealthy would"; but today we find that in Iowa there is an auto for every thirty-three people, and if the anticipations of the dealers are realized, they will make it unanimous in the near future.

And of all classes of men who could least afford to give up these once

luxuries, but now necessities, the farmer is the last. May we not then expect—what was true of the 'phone and the auto, will also be true of permanent roads? And when they have become a reality, the farmer will be the least willing to give them up.

Another thing I have noticed is, we get things pretty much as we need them, and the very fact that we are gathered here in a National Conference is evidence in itself that the cry for better roads is nationwide. That is another forward step in the onward march of civilization which, sooner or later, we must take.

And now, just a glance at that word "afford." Right here let me say, there is no more deceptive word in the English language, when measured by the dollar and cents standard. I stand here as a representative of the boys who could not afford to go to school, and no man knows better than I what that word has cost me. Again, gentlemen, no man can take a pencil and figure out a profit to the farmer from an auto, yet the auto has done more to uplift the occupation and place it on the high plane where it belongs than, perhaps, any other one thing. It has done more to keep the boys and girls on the farm than all the poetry and prose written in this country. And the man who wrote the poem saying the farmer toiled from sun to sun, but his good wife's work was never done, has been put to shame by the ode of the auto.

And I have come to this conclusion—that we can afford anything that is a forward step for the betterment of mankind, if we only think so.

And now, in closing, let me say, that I have great faith in the will of the American people. I believe we will take the forward step in the future just as we have in the past, and I believe we are fast approaching the permanent road age, and it may be even closer than we think, but when the time comes—when we have passed from the experimental to the practical stage of road building—when city has been connected with city and town with town—when the fantastic dreams of the most enthusiastic pipe-dreamers of hard roads have come true, and New York has again joined hands over a great concrete way with San Francisco—I give it to you as my opinion and as my prophecy, yea, as my pledge for the State of Iowa, that she will come forward and take her accustomed place in the building of roads, the place she now holds in the number of autos and 'phones owned. She will be in the front rank, in the first division and about half a step ahead of the other fellows.

THE CONCRETE ROAD SYSTEM OF WAYNE COUNTY, MICH.

ADDRESS BY EDWARD N. HINES, CHAIRMAN, BOARD OF COUNTY ROAD COMMISSIONERS, WAYNE COUNTY, MICHIGAN.

The laws of the State of Michigan provide a county system and a state reward system for the building of good roads. The county system is essentially the application of the home rule doctrine and no county can go into the building of good roads in Michigan under the county system without first adopting that system in that particular county. There are 83 counties in the state and of this number 58 are now under the system. Wayne was the twenty-seventh county. At the time the county road system was up for adoption there were two methods whereby a county could signify its wishes on the county system—one by means of the initial action of a majority of the board of supervisors, and the other by means of obtaining the signatures of 10 freeholders in each of the several townships, villages and cities. For a number of years, Wayne County was unable to get the sanction of a majority of the Board of Supervisors, nor could the county get the necessary 10 signatures from all the townships. It was not until 1906 that the necessary 10 signatures of freeholders could be secured in 3 of the townships. Finally, however, enough men were won over to the cause to put the county system up for adoption and the system was adopted by a vote of approximately 40,000 for to 7,000 against. The vote showed the real sentiments of the people on the road question, but when a board of county road commissioners was appointed a legal struggle ensued and the commission was rejected. However, a new commission was appointed and the real work of concrete roads was begun.

The first contracts accepted by the County Road Commission of Wayne County called for a bituminous type of road. After a year's experience, however, that commission, of which I was a member, found, just as road-builders are finding everywhere, that where the traffic is mixed, the bituminous type of road or the water-bound type does not stand up without excessive cost for maintenance and repairing, so we began to look for a new type of road construction because we did not believe it was advisable to continue the building of types of road that were failures. We had observed the action of concrete under traffic in cross walks, in bridge floors and in other places; we figured that if concrete would withstand the wear of traffic in those places it would probably stand up as a road if it were properly designed and properly built to meet the requirements.

We devised specifications for concrete roads and began to build them. We started work in April, 1909, and opened our roads in June of the same year. These first concrete roads are now in their fifth year and will soon start upon their sixth. Our roads have been inspected by almost every road-building expert in the country and the roads speak for themselves.

Wayne County is flat to a very large extent with a sub-grade composed very largely of clay. The county is in a valley and here and there are found occasional stretches of deep sand. When we adopted the county road system

there was not a single mile of good road in the whole county. There are 1,379 miles of road in the county outside of the villages and cities of which about 150 miles are now improved.

In the old days, the roads were almost impassable. During 4 or 5 months of the year certain farmers living along bad roads made a living by pulling heavy loads across the bad spots, and there are still a few such bad spots in the county on roads which have not been improved. It is often necessary for milk dealers or truck farmers to use 4 horses to get their loads upon the concrete. Once they are on the concrete they can trot the rest of the way to market with a single team. Ira Wilson, who is one of the leaders in the Milk Producers' Union in the county, told me the other day that before the road was completed to his farm it was necessary for him to use 4 horses to get his milk to Detroit. One team made the 16-mile trip one day and another the next day. Since the road has been built Mr. Wilson has purchased a motor truck and goes to town twice a day, carrying twice as much milk on his truck on each trip as he formerly handled with the horses.

One of the reasons why we gave up the building of macadam roads in Wayne County was because of the inability of macadam to stand up under automobile traffic. At slow speed the macadam road is not greatly injured by automobiles, but at high speed the macadam is stripped of the binding material holding the larger stone particles of the macadam road together. One advantage of the concrete road over the macadam road is that concrete is not dusty. The dust which an automobile raises on a macadam road, besides being a menace to health, is good stone dust that is badly needed on the road and is not needed at all in the fields where it usually settles. No oil or special preparation is necessary to keep the dust down on the concrete road. The drier the weather the cleaner the road. The only dust that is to be found on a concrete road comes from mud that has been tracked on the concrete.

As soon as we were convinced that our concrete roads were the proper type of road construction we began to devise ways and means of building them economically. One thing that we did was to establish storage yards at convenient points in the county. Another thing we did was to erect buildings in which to house our machinery during the winter months. In these same buildings we have provided shops for the repair of the machinery we use. While our road building equipment cost us a considerable sum of money, nevertheless it has been the means of saving the county far more than it has cost. We use wagons of the type best fitted for our needs. We use concrete mixers which we have found to be the most advantageous—the type of mixer that travels under its own power and has a projecting beam which can be swung in the arc of a half circle. We use steam shovels to unload our material from the cars and have unloaded as high as 27 cars with 1 shovel in 10 hours. When the material is unloaded from the cars into one of our storage yards we often find it advantageous to haul 4 or 5 wagon loads of it to the job behind steam rollers or traction engines. The stock piles enable us to continue our work without interruption in spite of the intermittent delivery of materials. We lay water pipes along the sides of our road and pump the water with gasoline engines from the nearest available supply.

In order to avoid delay in the work we establish road camps at the various jobs. During the busy season we employ from 800 to 1,200 men and the cost of feeding each of them amounts to $4.50 a week, but we

believe that the money we spend in feeding our men and making them comfortable is more than offset by their increased efficiency.

When we begin work on a road we begin in the winter by building our own tile for drainage purposes. Wayne County does all its own work, makes its own tile, builds its own concrete roads and maintains and looks after the county roads in general. Usually in taking care of drainage we tile with 4-inch land tile along street car lines and have an open ditch alongside of the road. When spring opens our scarifying is done behind a steam roller, our grading is done with a steam roller, our hauling is done with steam rollers and traction engines. We do not believe in putting men at work on anything that a machine will do as well, as cheaply, or as quickly, and we have worked out a number of little economies that improve the quality of the work and cut down the cost.

As soon as our drainage is cared for and our roadbed is prepared we haul our material to the job and pile it conveniently alongside of the road. We endeavor to pile our material in such a manner that as our mixer backs up our supply of material will remain in easy reach.

Our roads are constructed from washed and screened gravel ranging in size from ¼ to 1½ inches and washed and screened sand. We are very particular to have our aggregates free from clay, loam and other foreign substances. We use gravel in the construction of our roads because we have no other local stone available that is satisfactory. The limestone in Wayne County is very soft, so we purchase gravel of the proper quality because we can buy it at a cheaper price than we can buy any other material.

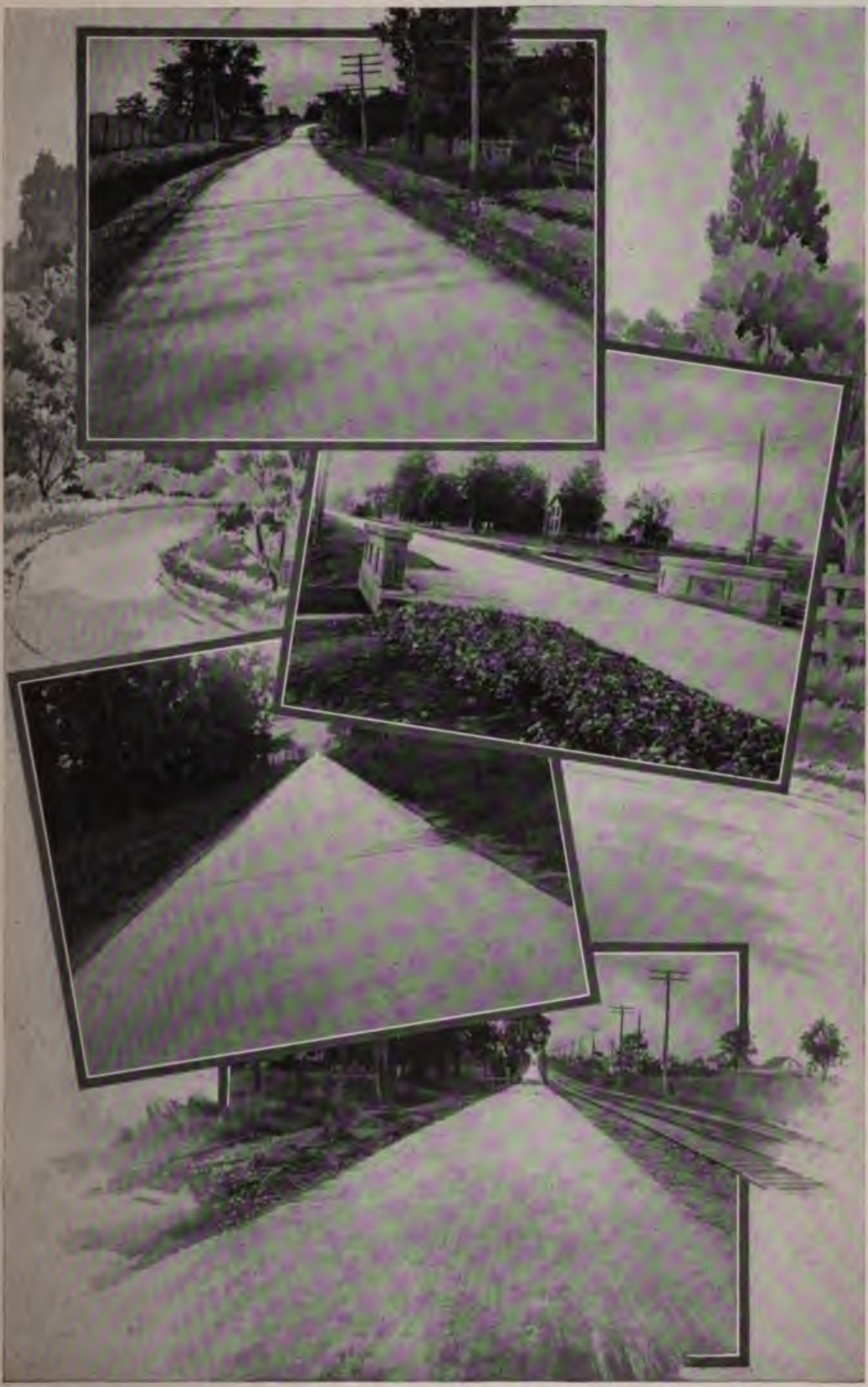
When our materials are in place along the roadside we set our side forms. At intervals of 25 feet we set in place the steel plates which we use to protect the pavement at the expansion joints. These plates are of soft steel about 3 inches in width and 3/16 of an inch in thickness with shear members which extend out 6 inches on each side into the concrete.

We utilize a rich mix of concrete because we believe it pays to use plenty of cement; the function of the cement is to act as the binder. The mix we use is nominally 1:1½:3. In reality, the mix is 1:3 with sufficient sand to fill the voids—about 7 per cent or 8 per cent plus. We use a wet mixture and in mixing we specify that the concrete shall be turned about 50 or 55 seconds. We have made some few tests on turning the mixer, 4, 8, 12, 16, 20, 24, 28 and 32 revolutions, and we find that the average from the revolutions at 16 over those at 12 to 28 shows an increase in strength of about 25 per cent.

Before we place the concrete we wet down the subgrade thoroughly to prevent its taking moisture out of the concrete. In placing concrete we utilize the side rails. These side rails are steel shod and the templet we use, which is cut to form the crown of the road, is also steel shod.

After the concrete is in place we do not permit anyone to step on it or to throw anything on it or interfere with it in any way. The final finish is made with wood floats, which keep the road from being slippery. The edge of the road is pared down about 3 inches so that there will not be too sharp a division line between the edge of the finished concrete and the earth, gravel or macadam alongside.

To prevent the concrete from drying out too rapidly we cover it with any material which is handy at the roadside and sprinkle it continuously for at least 8 days. We keep the traffic off for at least 2 weeks in warm weather and as long as 6 weeks in cold weather.



Four of Wayne County's Concrete Highways

Our concrete roads offer the best of service 365 days in the year for all types of vehicles. They are not slippery in wet weather nor are they dusty in dry weather. The traffic to which some of them are subjected approximates 2,500 vehicles a day. We have spent less than $100 a mile to maintain the first roads we built for the 5 years that they have been down, and in view of the service of the roads and their low cost of up-keep we consider our concrete pavements a good investment.

In connection with the maintenance of these concrete roads I want to cite an interesting incident. Rouge River is the only river in Wayne County that overflows its banks. It is spiled with a retaining wall at a point on Michigan Avenue Road, and that retaining wall was washed out a year ago. The concrete road alongside of the river was undermined 3 feet. It was undermined early in March and it was June before we could get to the road to fix it up. The road sustained the traffic during that time. We posted danger signs and warning signs to keep people off the edge, but farmers and others did not keep off the edge so we eventually put piles of earth and lanterns along the edge to keep them off. The traffic was carried over the washed-out part of the road for a matter of 9 weeks without any apparent harm to the concrete.

In Wayne County you will find boys roller-skating into the country delivering papers on these concrete roads; you will find children going to school; you will find city business men delivering coal and ice into the country; you will find farmers hauling larger loads into the city, and I think you will find the community at large well satisfied with the pavements; at least we now have on file from every section of the county enough petitions to build concrete roads to keep us busy for the next 10 years, building roads at the rate of 30 miles a year.

There are a number of gratifying features in conjunction with the road work that has been done in Wayne County. For instance, last year Detroit issued over $31,000,000 worth of building permits, yet in terms of percentage, for the first time in the history of the county, Wayne County, outside of Detroit, increased its assessed valuation to a greater extent than the city of Detroit.

There are two local sources of revenue for the building of our county roads. One is a direct tax levied on all the people of the county to be expended outside of the cities, and cannot exceed 50 cents on $1,000. The other is by bond issue. After we had been building concrete roads for a year people were not satisfied with the progress we were making, and they wanted to issue bonds for $2,000,000, to be spent in one year. The county Road Commissioners had not a sufficient organization to do this and finally a compromise was effected to spread that expenditure over a period of 5 years. We are now in the fourth year. We will have $500,000 available during 1914 for road building.

Last year, with the building of the Plymouth Road, we abandoned every other type of construction and adopted concrete entirely.

Now, gentlemen, we do not claim for the concrete road that it is a panacea for all road ills. We are proud of our roads. We have one section of road that is the longest concrete road in the world. It extends out from Detroit 28 miles. It is the Michigan Avenue Road, called the old Chicago Road. Besides this, we have a goodly mileage of concrete in the county which makes Wayne stand out as one of the foremost road counties in the country. We do claim, however, that our concrete road has

merit and that it is well worth the investigation of any community. In our locality we can build concrete for half the cost per square yard of any other so-called permanent pavement. We would insult your intelligence if we told you that we had not made mistakes. We have made mistakes—lots of them—but we have not made the same mistake twice. We have learned something, however, and any information that we have available is yours for the asking.

EXPERIMENTS WITH CONCRETE FOR ROADS CONDUCTED BY THE UNITED STATES OFFICE OF PUBLIC ROADS

ADDRESS BY J. T. VOSHELL, SENIOR HIGHWAY ENGINEER, UNITED STATES OFFICE OF PUBLIC ROADS, WASHINGTON, D. C.

Prior to 1911 the Office of Public Roads had no money available to pay any part of the cost of constructing experimental roads. All that it could do was to furnish engineering and laboratory aid to co-operate with such communities as were desirous of its co-operation and were willing to furnish all labor and materials. Therefore the character of the experiments in road construction conducted by this Office, prior to this time, were more or less controlled by the wishes of the local communities and no extensive experiments with concrete were made.

A description of these early experiments will be of little interest except it be from an historical standpoint and as illustrative of early attempts at building concrete roads. No very definite conclusions can be drawn from them as to what may be expected of more recent work and possibly their greatest value has been to illustrate the wrong way of building concrete roads rather than the right way. For example, all of the earlier sections were built by depositing on a prepared subgrade or foundation a fairly dry mixture of concrete which was spread and tamped in place by hand, and although great care was exercised in this work the surfaces of the roads so built were not smooth and therefore not in a condition to best resist the wear of traffic.

The Office of Public Roads has constructed experimental concrete roads at Ithaca, N. Y., Washington, D. C., in the Borough of Richmond, New York City, Bergen County, N. J., Borough of Queens, New York City, and Montgomery County, Maryland. As already indicated the methods employed in the first experiments have not proved satisfactory, but in order to show the evolution in the methods of construction a brief description of all of the experiments will be given.

In 1909 Cornell University invited the Office to co-operate with it to ascertain the relative value of different road building materials and of different road surfaces. The invitation was accepted and some twenty-five experimental sections of road were built, two of which were of concrete. The concrete sections were built on Forest Home Drive, just west of Sibley College, and have been subjected to a rather heavy automobile traffic and a considerable amount of country traffic. These sections, one 530 feet in length and the other 35 feet in length, consist of a foundation course of crushed limestone and a wearing course of concrete laid to a finished depth of four inches. The concrete of the 530-foot section is composed of 1 part of cement, 2 parts of sand and 5 parts of crushed limestone and that of the 35-foot section is composed of one part of cement, two parts of sand, and 6 parts of cinders. The cement was a standard brand of Portland cement conforming to the requirements of the usual specification. The crushed limestone for the coarse aggregate was furnished in two sizes, one ranging from 1¼ to 2¼ inches and the other from ½ to 1¼ inches. The

percentages of voids were determined for each size of stone and for various mixtures of the two sizes. It was found that the percentage of voids was lowest in a mixture consisting of 5 parts of the larger stone and 3 parts of the smaller and this mixture was used in the work. The cinders were from the University heating plant.

All of the concrete was mixed in a stationary batchmixer, hauled about 300 feet in a dump wagon and dumped upon a mixing-board from which it was shoveled into place and leveled with steel hand rakes. It was then tamped by hand with concrete tampers until mortar flushed to the surface, after which it was rolled with a hand roller until the surface was fairly smooth. The work was done in the late fall and the concrete, as soon as it was laid, was covered with leaves to protect it from freezing. The leaves were not sprinkled and were removed after a period of 15 days. Traffic was then permitted over the road.

It had been planned to apply several different bituminous materials to a corresponding number of short sections of the road surface, but approaching winter and inability to secure the materials prevented the carrying out of all of these experiments except one. This experiment consisted of applying an oil-asphalt to a section of the road surface 30 feet in length. The oil-asphalt, having a penetration of 16.8 millimeters at 25 degrees centigrade, was heated to about 300 degrees fahrenheit, applied at the rate of 1 gallon per square yard and covered with stone chips. The surface of the concrete was damp and cold and the oil-asphalt did not adhere to it and by the following spring the greater part of it had worn away.

During the summer of 1910 different sections of the concrete surface were treated with a refined semi-asphaltic oil, an oil asphalt, a refined coal tar, and a refined water-gas tar. The results of these experiments were not very satisfactory as the bituminous coats were soon worn through along the center of the road and at the end of a year there was not much evidence to show that they had been applied except a thin dead mat along each side of the pavement. Since that time the entire concrete surface has been annually treated with a bituminous material.

At the present time the concrete road does not present as good an appearance as is now obtained by modern approved methods of construction, but it has nevertheless proved serviceable and does not show excessive wear. Soon after the limestone concrete section was laid a longitudinal crack appeared about 3 feet from the south edge, which led to the development of a long shallow rut. This was due to a poor foundation along this side of the road. The cinder concrete section has a smoother and generally more attractive surface than the other, but appears to have worn down about ½ inch more than the limestone concrete section. No transverse cracks have been observed in either section.

During 1909 the Office of Public Roads conducted a series of laboratory experiments to determine the effect of mixing with ordinary concrete a residual petroleum at the rate of from 3 to 5 quarts per bag of cement. It was found that the strength of the concrete was not materially impaired, that it absorbed much less water and that the early shrinkage due to setting was much reduced. Therefore it seemed probable that this oil-cement concrete might be better suited as a surfacing material for roads than plain concrete and the experiments conducted during 1910 and 1911 were for the purpose of giving this material a practical test.

In co-operation with the District of Columbia, seven sections of concrete pavement, having a total length of 356 feet, were laid on Meridian Place.

Six of these sections were of oil-cement concrete and one of plain concrete. A description of these experiments will not be given, as in less than a year after the pavement had been laid, sixteen openings, each more than a square yard in area and distributed throughout the length of the pavement, were made for the purpose of repairing a sewer. No attempt was made to restore the pavement to its original condition and therefore no proper conclusions could be drawn as to the relative values of the different sections or of the value of the pavement as a whole.

In co-operation with the Borough of Richmond, New York City, four sections of oil-cement concrete, having a total length of 444 feet, were laid at Port Richmond on that part of Innis Street lying between Morning Star Road and John Street. The sections differ from each other in that a different brand of cement was used in each, and in that each contained a different oil content. A residual petroleum oil and a cut-back petroleum residue were each used in two sections in an amount equal to 10 and 15 per cent by weight of the cement. The concrete of each section consisted of 1 barrel of cement, 8 cubic feet of sand, 16 cubic feet of crushed stone ranging in size from 3/4 to 1 1/2 inches, and 40 or 60 pounds of oil. It was mixed in a stationary batchmixer, wheeled to its place in the road and spread to a uniform depth of 4 inches, after which it was tamped until mortar flushed to the surface. The work of laying the concrete was carried on over the full width of the street and no header was set against which the day's work would be finished. Neither were transverse or longitudinal expansion joints constructed. On account of omitting the header a sloping joint was formed and as a result the pavement has worn excessively at these joints. Quite a number of longitudinal and transverse cracks have appeared and a section about 50 feet in length, near the center of the experiments, has cracked so that the cracks form a very good outline of a huge spider-web. In one section the concrete seems to be of very poor quality and a number of shallow holes have developed. Taken as a whole these sections are in poor condition.

In co-operation with Bergen County, N. J., in June, 1910, the wooden floors of two small bridges were removed and replaced with oil-cement concrete. One bridge is 25 and the other 37 feet in length. The concrete was laid 6 1/2 inches thick at the center and 4 1/2 inches at the sides on iron sheathing and reinforced with chicken fence wire. The concrete was composed of 1 part cement, 2 parts of sand and 4 parts of crushed trap rock ranging in size from 1/4 to 3/4 inch, and oil to the amount of 15 per cent by weight of the cement. It was mixed by hand, shoveled into place and well tamped. When inspected in January, 1914, these floors showed little evidence of wear, and no signs of cracks. All the wear that was noticeable was that where the floors join the macadam roadway the edges are slightly rounded.

In 1911, in co-operation with the Borough of Queens, New York City, a section of oil-cement concrete, 173 feet in length and 24 feet in width, was laid on Hillside Avenue. This avenue is the principal thoroughfare from New York City proper to Long Island, and a traffic census taken showed that an average of 1,830 vehicles pass over it each day.

The concrete was composed of 1 part of cement, 2 parts of sand, and 4 parts of crushed trap rock ranging in size from 1/4 to 3/4 inch and oil to the amount of 10 per cent, by weight, of the cement. It was mixed in a stationary batchmixer and wheeled to its place on the road in wheelbarrows, spread with rakes to a uniform thickness of 4 inches, and tamped

until it was well compacted. To correct the slight irregularities in the surface a mortar mixed in the proportions of 2 bags of cement, 2.5 cubic feet of sand, 7.5 cubic feet of trap rock screenings, and 8 quarts of oil was spread over the entire surface to a depth of about ½ inch and brought to a smooth surface by floating with a wooden float. On a section, about 10 feet in length, the irregularities in the surface due to tamping were corrected by casting over the surface a dry grout composed of 1 part cement and 2 parts of trap rock screenings. When traffic was admitted to the road these chips were soon thrown aside and were of little if any benefit. Only one expansion joint was constructed and that near the center of the section. It consisted of two courses of wood block 3 inches in width and 4 inches in depth laid on a sand cushion. The joints between the block and between the block and the concrete were filled with a native fluxed asphalt having a penetration of 13.0 millimeters. This expansion joint is now in as perfect condition as when it was first constructed. The edges of the concrete seem to have been perfectly protected.

In May, 1912, this pavement was inspected and it was found that there were several small areas which showed considerable wear and the entire surface was treated with bituminous materials. A refined coal tar, an oil asphalt and a tar-asphalt preparation were respectively applied to different sections of the surface and covered with sand or stone chips. By June, 1913, there were several small areas in the coal tar section from which the tar was missing, practically all of the tar-asphalt preparation was gone and about 50 per cent of the area of the oil-asphalt section was bare. The entire surface of the section was then cleaned off and a refined coal tar applied to one-half and a refined water-gas tar to the other half at the rate of ½ gallon per square yard and covered with plenty of rather coarse sand. In January, 1914, the entire section was in very good condition.

Beginning with 1911, Congress has annually appropriated money whereby the Office has been able to pay part or all of the cost of constructing sections of road for the purpose of determining the relative values of the various road building materials and the various road surfaces. Since this time the Office has undertaken and carried out more extensive experiments than had before been possible and has also been able to dictate the nature of the experiments.

Accordingly in 1912, in co-operation with Montgomery County, Maryland, a series of experiments were carried out to determine the relative value of bituminous concrete, cement concrete and brick road surfaces when laid according to the best modern practice. These experimental sections, having a total length of 6,195 feet, were laid on Kensington Road beginning at Bradley Lane and extending to Chevy Chase Lake. The road has a double track street car line down the center of it and the section paved is a strip, 20.5 feet in width, on the west side of the street car line.

All of the work was done by a contracting company, which had had extensive experience in paving work, according to plans and specifications prepared by the Office of Public Roads. And while the work was well and faithfully done no extraordinary effort was made to secure a "sandpapered" job, and the work is representative of what should be expected from a good contractor.

The concrete section, 3,950 feet in length, was built not only to determine the relative value of concrete as a material for surfacing roads but to determine the relative value of plain concrete and oil-cement concrete, the *relative values of* gravel, crushed limestone and crushed trap rock for coarse

aggregate, whether or not expansion joints were necessary, and, if so, the proper spacing for them, and to determine the relative values of various bituminous materials when used for a carpet or paint coat on the concrete surface. Therefore sections of plain and oil-cement concrete were built, on which the various bituminous materials were applied, and in which the above mentioned coarse aggregates were used, and the entire section was built without any joints excepting such construction joints as were necessary at the end of each day's work.

In the plain concrete the materials were mixed in the proportions of 1 part of cement, 1¾ parts of sand and 3 parts of coarse aggregate and sufficient water to form a concrete of a "mushy" consistency. In the oil-cement concrete the same materials were mixed in the same proportions as in the plain concrete, and in addition a residual petroleum oil was added at the rate of 5 pints of oil per bag of cement. The coarse aggregates ranged in size from that passing a 1½-inch screen to that retained on a ¼-inch screen; the sand was a good concrete sand obtained from the Potomac River; and the cement was a standard brand which met the requirements of the "U. S. Government Specifications for Portland Cement." All of the concrete was mixed in a street paving mixer, equipped with a rotary distributing device, which deposited the concrete practically in place upon the subgrade. After the concrete had been deposited to a depth of slightly more than 6 inches, it was carefully "struck off" with a "strike-board." The surface was then floated with a wooden float.

To determine the changes in length of any section of the concrete road due to changes of temperature, brass plugs were embedded in the concrete, just before the final floating, in two rows 5 feet from the edges of the pavement; one row with a 10-foot spacing and the other with a 50-foot spacing.

When the concrete had partially set it was covered with paraffined canvas which remained in place until the concrete was hard enough for the surface not to be damaged by men walking upon it. The canvas was then removed and the concrete covered with a 2-inch layer of sand or earth which was kept wet for a period of 10 days. The construction joints were made by setting a header perpendicular to the subgrade and at an angle of 80 degrees with the center line of the road.

When the sprinkling was discontinued and the concrete began to dry out, transverse cracks began to appear. The cracks did not appear at regular intervals, and their location was undoubtedly somewhat controlled by joints in a concrete gutter, which had previously been built along the road and against which the pavement was laid, as a majority of the cracks in the pavement appeared opposite joints in this gutter. By the time the concrete had thoroughly dried out, the cracks were an average distance of about 75 feet apart. A few more cracks appeared during the following winter, since which time none has developed. At the present time the average length of the monolithic sections is 43 feet where gravel was used as a coarse aggregate and 121 feet where crushed stone was used as a coarse aggregate. The shortest monolith is in a gravel section and is 15 feet in length, while the longest monolith is in the crushed stone section and is 220 feet in length.

Measurements have been taken from time to time between the brass plugs, heretofore referred to, with a 10-foot strain gauge so designed as to measure accurately to 1/1000 of an inch, and it has been found that the concrete changes in length with a change of temperature in an amount quite near *what would be obtained by* applying the factor for the coefficient of

expansion of concrete, and making a reasonable allowance for friction on the subgrade, thereby showing that the concrete contracts more at the time of setting than it expands due to subsequent rises in temperature.

Of course the width of the cracks changes as changes in temperature occur but ordinarily they appear to be from 1/16 to ⅛ inch in width. The largest cracks occur between the ends of the longest monolithic sections—those occurring at the ends of the 220-foot monolith have an average width of about ¼ inch. If these cracks were to become filled with relatively incompressible material it is evident that compressive stresses would be developed in the concrete and would have to be taken up by the elasticity of the material. The maximum and minimum temperatures of the pavement so far observed were respectively 115 degrees and 25 degrees fahrenheit and the pavement shows no signs of having, in the least, been damaged by this variation of temperature.

The edges of the cracks have been broken off to some extent by traffic, though not to such an amount as to be of much damage to the pavement. Those in the sections in which gravel was used as a coarse aggregate have broken off to a much greater extent than those in the crushed rock sections and all have broken off more than the edges of the construction joints in the same sections.

Last May a refined coal-tar, a refined water-gas tar preparation, a fluxed native asphalt and an oil asphalt were respectively applied to different sections of the plain and oil-cement concrete which had been laid the previous November. The surface of the concrete was thoroughly cleaned by sweeping and washing and the bituminous materials were applied hot by means of a hand distributor at the rate of ½ gallon per square yard, after which a layer of stone-chips or ⅜-inch gravel was spread over the surface and rolled with a 5-ton tandem roller.

In addition to the 8 sections above mentioned, bituminous materials were applied to 2 other sections of the concrete surface. The sections were cleaned as above described and the surface of one was painted with an emulsified native asphalt at the rate of about 1/10 gallon per square yard and the other with a light refined water-gas tar at the rate of about 1/5 gallon per square yard, after which a fluxed native asphalt was applied as above described at the rate of about ½ gallon per square yard.

At the present time there is no apparent difference between the corresponding sections applied to the surfaces of the plain concrete and the oil-cement concrete. There is, however, a difference between the sections coated with the different bituminous materials. The sections to which the refined water-gas tar preparation was applied are in a very good condition, as there are relatively few bare areas, the bituminous material is flexible and adhesion between it and the concrete surface is good. The refined coal-tar sections are in fair condition, but there are numerous small bare areas and while adhesion between the tar mat and the concrete surface is good the tar appears to be rather "dead." The sections treated with the fluxed native asphalt and the oil-asphalt are in good condition on the east two-thirds of the road but on the west third there are a number of rather large bare areas. The asphalts are flexible but do not appear to adhere well to the concrete surface. The section to which a paint coat of light refined water-gas tar was applied is in good condition—the bituminous materials are flexible, adhesion with the concrete surface is good and few bare areas occur. The section to which a paint coat of emulsified asphalt was applied is in fair condition on the east half of the road, while on the west half about 40 per

cent of the concrete surface is bare. Adhesion between the asphalt mat and the paint coat appears to be poor.

A section, 50 feet in length, was treated with a crude water-gas tar at the rate of about 1/10 gallon per square yard. This penetrated the concrete to such an extent that the surface at the present time has a dark brown color. There was not sufficient material to form a mat and it does not appear that this treatment is of any value in protecting the concrete surface from wear. However, it appears to be an efficient method of coloring a concrete road to obviate the more or less objectionable glare due to the sun shining on a white concrete pavement.

From the experiments conducted by the Office of Public Roads the following conclusions appear to be justified: The surface of the road should be smooth and uniform and to obtain this in a most practical manner rather wet concrete should be used. The coarse aggregate should be relatively small, preferably one in which all of the particles will pass a 1¼-inch screen. The concrete should be rich in cement in order that the mortar may be sufficiently strong and tough to resist, to a considerable degree, the wear of traffic and to hold the particles of the coarse aggregate in place. Transverse contraction joints should be constructed but expansion joints seem unnecessary. Particular attention should be given to the curing of the concrete by covering it and keeping it wet to insure that the mortar will have the essential qualifications of strength, hardness, and toughness, and in order that sufficient tensile strength may be developed, before initial shrinkage occurs to prevent cracks from being formed between joints. These conclusions are only qualitative. It is hoped, however, that these experiments may eventually furnish sufficient data to warrant, at least, a few definite quantitative conclusions.

DISCUSSION

Mr. McIntyre:—I would like to ask Mr. Voshell if he noticed the same condition which I did upon the sections covered with the bituminous covering. I noticed that the traffic, the heavy loaded teams, came along in one direction, that is, from the south of the station, which was down at the bottom of the hill at the end of the road. The bituminous mat came off in places where that heavy traffic was, but on the other side of the road, which took light driving, the bituminous mat stayed in position.

Mr. Voshell:—Yes, sir, that is correct.

Mr. Spackman:—I would like to ask Mr. Voshell whether there is any difference between heavy hauling on a plain concrete surface and a surface covered with a bituminous carpet.

Mr. Voshell:—The section covered with the bituminous carpet is on about a 2 per cent grade, and the greater part of the balance of the concrete is on a 3 per cent grade. We made inquiry of some of the teamsters using the road and they expressed themselves as seeing no particular difference, except that in very cold weather they found the sections having a bituminous carpet slightly more slippery than the plain concrete sections.

Mr. Gerber:—I would like to ask how the oil was applied to the concrete, whether in an emulsion or after the water was applied.

Mr. Voshell:—In the oil-cement concrete the oil was poured into the mixing drum after the charge was thoroughly wet. Care was exercised to prevent any oil coming in contact with dry aggregate.

CONCRETE ROAD CONSTRUCTION BY TH
OHIO STATE HIGHWAY DEPARTMENT

ADDRESS BY H. D. BRUNING, DIVISION ENGINEER, OHIO STATE HIG
COMMISSION, COLUMBUS, OHIO

The operation of the State Highway Department of Ohio is co to the construction, improvement and maintenance of certain roads, desi as inter-county highways, which form a system connecting the principa ters of commerce within the state. Being thus the main arteries of t they demand an improvement which will bear the burden of traffic of m and heavy density. No detailed traffic census has been undertaken b Department, and the decision as to the kind of pavement to be used i wholly dependent on the character and amount of traffic, but in a measure on the character of materials easiest at hand. Where traffic ditions are the deciding factors, local authorities are consulted as to pr traffic, and an estimate made as to the probable growth due to the imp ment and the increasing commercial activities. Owing to the wide a ability of materials suitable for first-class concrete construction in the s the concrete road has found its place among the several types of roads use the Department. The total mileage of concrete roads completed to da 39.63 miles, and the mileage under construction and let, 25.06 miles, ma a total of 64.69 miles. The first concrete road constructed by the Depart was completed in July, 1911, and the total mileage of concrete roads structed, under construction and let, represents about 18 per cent of the mil of all classes of roads put under contract since that time. It is thus appa that the concrete road has a great prominence in the road-building a Ohio, and the demand for such roads is growing day by day. Such dem often come from farmers and other users of horse-drawn vehicles, w seems to eliminate the oft quoted objection that this type of road, w untreated with a bituminous mat, is hard on country-bred horses.

The materials for aggregates of concrete are distributed over the en state, and nearly every mile of road in the state is within reach of t materials at a reasonable haulage distance. The western half of the s is an area where limestone is abundant, and the eastern part is supplied t great extent with furnace slag dumps. Again, the northern and west section of the state is covered with a mantle of clay, sand and gravel, res directly on the hard bed rock. This mantle was brought in and depos by the great sheet of ice which at one time covered much of North Amer The melting of this sheet of ice formed waters, which assorted the gla materials, and deposited it in beds of clay, sand and gravel. Thus vast b of gravel remain in the valleys of the Ohio, Muskingum, Hocking, Mi and Scioto Rivers. Some 150 quarries, operating in the limestone belt, 30 sand and gravel washing and screening plants are shipping their prod into the markets of the state. In addition to these, local sand and gra deposits and limestone quarries are found in sections where railroad facili are not at hand. Thus it may be said that no section of the state can found where concrete materials of prescribed character are not available wit reasonable hauling distance.

RE

Coarse Aggreg	reatment	Remarks
Washed River Gr		4"Concrete on slag macadam foundation
Silica Pebbles	ood	
Crushed Limest		
River Gravel		
Screened Gra		
Slag & Washed River		Wavy Surface
Crushed Limest		Rough Surface
Crushed Limes	ood	
Crushed Bould nd Quality Grave		2 Course Concrete
Crushed Slag		Artificial Drainage
Washed River Gr		
Washed Gravel		Road located on Reservoir bank
Unscreened Gr		Concrete worn considerably
Unscreened Gr		One 90ft section has 4 transverse cracks
ed Bank Gravel	rn	Concrete disintegrating in several places
Washed Grav		Has successfully withstood a 10 foot cover of water with strong current
Crushed Bou		
Washed Grav		Transverse crack on 60 foot section
ned Bank Grav		Concrete re-inforced
ned Bank Grav		
Crushed Limes		
Crushed Limes		
ned River Grav		
Crushed Bould		Has successfully withstood a 10 foot cover of water with strong current
ed River Grav		
Crushed Slag		
Crushed Slag		
Washed River		
River Gravel		

ructed

The term concrete roads, as used heretofore, and used hereafter in this paper, means cement-concrete roads. Three types of concrete pavements have been constructed by the Department, namely: Single course plain, two-course plain, and single course reinforced. The standard type is the single course plain concrete pavement laid on the natural foundation, except in the case of road No. 1, where on about one-half of the road a 4-inch slab was laid on a waterbound slag foundation, which is giving entire satisfaction after 18 months' use.

A two-course pavement (Road No. 9) 12 feet wide was constructed in Lake County during the season of 1913. The aggregate in the base course is unscreened second quality gravel, and those in the wearing course are crushed boulders and bank sand, all found locally. The cost of this improvement would have been excessive had the material been shipped in, on account of the long haul of 7 miles from the nearest railroad delivery point. The wearing course was laid before the base course had begun to set, never more than 15 minutes elapsing between the placing of the two courses. A very satisfactory bond was obtained and to date no separation between the courses nor cracks are visible in the concrete.

Two single course reinforced pavements (Roads Nos. 5 and 20) were constructed in Harrison and Pike Counties in 1911, being the first concrete roads constructed by the Department. In both cases the work is located on roads that are subject to overflow, and it was partly on this account that concrete was selected. The concrete made in the weak proportion of 1 part cement, 2½ parts sand, and 5 parts gravel was reinforced with No. 11 wire, woven to a 6-inch mesh. The reinforcing was placed midway between the upper and lower surfaces. Transverse joints were placed every 50 feet at an angle of 45 degrees with the line of the road. The surface of the concrete was rough floated with a plank templet giving a safe footing for horses. Careful inspection of both roads after about 2½ years' service shows that no cracks are apparent in the road in Pike County, and only 4 sections of the 1.25 miles in Harrison County were cracked transversely, but the size of the cracks is inappreciable. The joints on both roads show considerable wear, due largely to the oblique direction. In general the concrete, although lean in the proportion of cement, shows very little wear.

The importance of a well-prepared sub-grade in concrete road construction has been recognized in all the work done. The specifications have been closely followed in the matter of uniformly compacting the roadbed with a self-propelled roller, weighing not less than 6 tons; all depressions which develop during the rolling are filled with acceptable material, and re-rolled until the entire roadbed is uniform in cross section and thoroughly compacted. No special provision for drainage of the sub-grade has been found necessary, as in all cases the sub-soil has not been retentive, and ample drainage is secured through the side ditches. To date no set standard cross-section for the pavement has been adopted. Three types of cross-sections have been used: 1—A uniform thickness of concrete over the entire width of the pavement, forming the same amount of crown in the surface of the sub-grade as in the concrete surface. 2—A greater thickness of concrete at the center than at the sides, leaving some crown in the sub-grade. 3—A greater thickness of concrete at the center than at the sides, built upon a flat sub-grade.

No greatly differing results in the types are found in the permanency of the pavements *constructed, and it* would be difficult to select the type which

would exceed the other two in qualification to withstand the effects of heavy loads and extreme temperatures. A reference to the table will show the various thicknesses used.

The standard crown is ¼-inch to the foot. This has been found sufficient to insure perfect drainage of a concrete road with the usual small imperfections in the surface, and after the road becomes coated with a mat of dirt. The ability to drain itself with so small a crown at once becomes one of the merits of the concrete pavement.

Defects in the roads constructed do not point to any faults in the details of the design of the cross-section, as they do to the details of inspection. To assist in the matter of inspection, a well equipped laboratory is maintained by the Department, and all materials entering into the construction are given thorough standard tests. A very important requirement in first-class concrete construction is to get a sand of good quality, and where sand of a doubtful character is submitted, it is tested for tensile strength, the requirements of the specifications being that the tensile strength of briquettes made with the proposed sand shall not be less than the tensile strength of briquettes with standard Ottawa sand and the same cement. Cement is tested in car load lots.

The proportions now used in all concrete road construction by the Department are 1 part cement, 1½ parts of fine aggregate, and 3 parts of coarse aggregate. The proportions of the mortar are maintained uniformly 1 part cement to 1½ parts of fine aggregate, and the amount of coarse aggregate is varied somewhat for the different classes of material, so that there is an excess of about 10 per cent of mortar over the voids in the coarse aggregate as an advantage in finishing. Although the leaner mix used on the first two roads, namely, 1 part cement, 2½ parts of fine aggregate and 5 parts coarse aggregate, has given fairly good results, it was found necessary to employ the richer mix to assure absolutely satisfactory results. A lean mix requires much more care in mixing and placing, and it is in these items where causes of defects and failures in concrete roads are prominent. At least, this has been the experience of the Department.

The mixing is done by machine mixers of the type known as "Batch Mixers." No "continuous mixers" are allowed to be used. Before any work of mixing and placing of concrete is started, the engineer in charge determines the proper proportion of the coarse aggregate to secure maximum density and the excess mortar of 10 per cent above the amount required to fill the voids in the coarse aggregate. The materials are measured by methods which will insure uniform proportions at all times. Usually this is done in wheelbarrows, which are gauged accurately as to capacity; but in a few instances the measuring has been done in cubical boxes containing 1 cubic foot. Our greatest trouble in the past has been to maintain a uniform consistency of the concrete, but this trouble has been greatly alleviated since the contractors' forces are becoming more experienced in this class of work. The concrete is made sufficiently wet to require no tamping, but there is a strong tendency among the contractors to make it sloppy, which necessarily results in more or less separation of the coarse aggregate from the mortar. This tendency has resulted in the formation of waves on some of the heavy grades due to the creeping of the concrete. On the heaviest grade it is advisable to use a somewhat drier mixture, and this rule has been carried out in our construction wherever possible.

After the surface of the concrete has been shaped by the use of a templet, it is floated with a wooden float in such a manner as to thoroughly compact and seal the surface, and produce a surface conforming to the exact crown. No depression is allowed in the finished work which is greater than ½ inch from a 10-foot straightedge applied to the surface of the concrete and parallel to the center line of the pavement.

The specifications provide that within 1 hour after the surface of the concrete has been floated, a canvas covering shall be placed over it and left in place for at least 12 hours. This provision has not been carried out in all cases, but instead the surface has been kept wet by sprinkling. The sprinkling is continued for at least 5 days and in most cases a covering of sand, dirt or straw has been used to assist in retaining the moisture. This precaution is absolutely essential to secure the very best wearing qualities of the concrete.

A common point of failure in pavements thus far constructed is in the expansion-contraction joints, which on most of the roads have been placed at intervals of 30 feet, but in some cases, for reasons unknown to the speaker, a greater spacing was made. However, this failure is usually in cases where poured joints were used, and the speaker's observation is that this source of failure has been largely eliminated by the use of tarred felt joints. In one road (Road No. 14) Baker plates have been used and the results are fairly satisfactory, although some wear is apparent, due probably to the imperfect placing of the plates. A reference to the table will at once show that transverse cracks do not appear, except in rare cases, where joints are not more than 30 feet apart, but in all cases these cracks occur in large numbers where the joints have a spacing greater than 30 feet. On Road No. 14, Section 3, of the Piqua-Troy Road, one 90-foot section developed 4 transverse cracks; 6 sections, 3 such cracks, and 21 sections, 2. In no case do these cracks show any appreciable wear, but they will doubtless prove to be a source of annoyance in maintenance of the road after several years' service.

In this connection, it may be of interest to state that a 12-foot pavement, 6,946 feet long, was completed in September, 1912, by the county of Huron as a monolith. The aggregates were Bellevue crushed limestone and Canadian sand. Six sacks of cement were used per cubic yard of concrete. Over one-half of the road the thickness is 6 inches, and the pavement rests on clay sub-soil. Over the other half the average thickness is 5 inches, and the minimum 4 inches laid on old sandstone foundation. On inspection made last month, it was found that 85 transverse cracks had formed, ranging in spacing from 9 feet to 159 feet. The cracks are very irregular and several are badly worn. The same general condition both as to number and spacing of the cracks existed on each half of the road.

The much discussed question of the advisability of treating the surface of concrete pavements with a bituminous mat is being investigated very carefully by the Department. The results thus far obtained on 23 roads thus treated have rather discouraged further general application. The method of surfacing the concrete with the bitumen is as follows: After the concrete is well hardened, a period of not less than 10 days being specified shall elapse after the concrete has been placed, tar or asphalt heated to from 200 degrees to 250 degrees fahrenheit is applied, in quantity equal to ½ gallon per square yard, and spread uniformly over the surface. While the tar is still soft there is applied a layer of coarse sand or pea gravel in amount of one cubic yard to about 100 square yards of surface. This forms a mat varying in thickness from

⅛ to ¼ of an inch. Present specifications limit the covering to tar products and gravel, ranging in size from ⅛ to ¼ of an inch.

On inspection just made by the speaker and Division Engineer Harwood Lersch, the data obtained show that on only four out of 23 roads treated has the bitumen given good results, on all other roads it has peeled off in varying degrees as shown in table. An examination of the tar mat that peels off almost universally shows that the tar has adhering to its under surface a film of inert mortar, from 1/32 to ⅛ inch in thickness, that has been separated from the surface of the concrete. It thus seems that the peeling is not due to failure of the adhesion of the tar to the concrete, but the peeling is due either to an action of some ingredient in the tar on the concrete surface, or more likely to the nature of the concrete itself, which makes it possible for the tar to pick up the top film of the concrete. Where the treatment is an oil asphalt, this condition is not true, and it is the experience of the Department that such a product can not be successfully made to adhere to the concrete.

The life of a bituminous tar treatment (where the same adheres to the surface) depends upon many factors. To accurately determine these factors is somewhat of a problem. Examination of the various roads reveals that tar mat filled with sand wears off much faster than one filled with pea gravel, which will resist abrasion to a higher degree. The treatment of tar and sand on Road No. 11, Youngstown-New Bedford Road, indicates a probable life of not to exceed 2 years, same having worn down to a thin mat not exceeding 1/16 inch after a use of only 7 months under heavy mixed traffic. At a cost of 9.5 cents per square yard for such treatment, which is an average cost on all roads treated, the maintenance of same would be rather excessive.

An interesting fact has revealed itself on Section 19 of the South High Street Experimental Road at Columbus, constructed under force account by the maintenance bureau of the Department. A Dolarway treatment was applied at the rate of 0.36 gallon per square yard, and covered with coarse sand. The 33 feet at the south end of this section was given two applications of the tar and sand. The part given one application peeled badly, while the part given two applications holds, and is in good condition after 15 months' use under very heavy mixed traffic. The latter presents very much the appearance of an asphalt pavement. On Section 20 of this same road where Tarvia was used, what peeling has taken place has been on the parts which received the least tar.

Owing to the apparent short life of the bituminous wearing course as heretofore applied, it would appear in the light of present knowledge of the subject to be uneconomical to apply such surfacing, or attempt to maintain a bituminous top on the pavements thus far treated in this manner. However, the use of tar for treating cracks which develop in the pavement, and the use of tar and mineral aggregate for patching defects such as worn joints and holes, is very effective, and apparently the cheapest method of maintaining a good surface on such a road. Such repairs should be made at least once every year. The cracks, joints, or depressions should be swept clean of all foreign matter before the heated tar is applied. The mineral aggregate should be clean, thoroughly dry, and of a size practically as large as the depth of the hole. If fine material is used the traffic will drive the tar to the top. This tar concrete should be thoroughly tamped. While asphalt may be used for filling of joints and cracks, it is usually advisable to repair depressions in the surface at the same time, and for this latter purpose, tar has given the best results.

There are, of course, exceptions and situations that can be cited where possibly some advantage can be gained by the use of the bituminous surface treatment over the entire pavement, as for example in the case of badly cracked and checked pavements. To date, no systematic operation of maintenance has been developed by the Department, but a complete organization for maintenance, under the immediate charge of superintendents employed by the Department, is being perfected.

The average cost of the concrete pavements completed to date is $1.128 per square yard, as set forth in the table. This cost is the contract price paid and does not include the cost and expense of engineering and inspection, but does include the cost of grading and finishing of shoulders and ditches and a small amount of accessories. Deducting from this average cost the average cost of surface treatment, which is 9½ cents per square yard, there remains $1.033 as the average cost per square yard of plain concrete including grading, shoulders and accessories. The average cost of grading, finishing of shoulders and ditches and accessories is $0.167 per square yard of paved surface. Deducting this from $1.033 we have 86.6 cents as the average cost per square yard of the plain pavement alone exclusive of engineering and inspection costs.

Examinations of the details of the 29 roads completed, during and after construction, gives information from which we are able to draw the following conclusions:

1. That careful and intelligent inspection and the use of only first class material are essential to the construction of concrete pavements to insure permanency.

2. That the use of bank run gravel or crusher run limestone should not be permitted.

3. That a rich mixture is necessary as a factor of safety against irregularities in the mixing and placing of concrete.

4. That the wearing quality of the pavement is often greatly impaired by insufficient protection against too rapid drying.

5. That there is no apparent difference in the permanency of pavements constructed on either a flat sub-grade or on a sub-grade having a crown.

6. That the weakest points in the pavement are at the expansion-contraction joints and that tarred felt is preferable to a poured joint.

7. That the part of the shoulders next to the concrete pavement should be reinforced by placing stone or gravel macadam on 1 to 2 feet of the shoulders next to the pavement. This will avoid the usual formation of a rut in the shoulder which tends to retain the surface water.

8. That a bituminous surface treatment is not essential to a good concrete pavement.

9. That observations indicate there is no special value in roughening the surface of the concrete preparatory to putting on the surface treatment, and such roughening will tend to increase the wear if the surface coat is worn away and not replaced.

10. That asphalts used as a surface treatment for concrete have peeled more than tars.

11. That the results secured in the surface treatment of the present time do not warrant its use in great quantities, but experiments should be carried forward in sufficient number to learn further facts and establish, or disprove, those already thought to be known.

12. That first class concrete pavements have every indication of ability to stand up under heavy steel tire traffic.

REPORT OF COMMITTEE I

CONTRACTION AND EXPANSION OF CONCRETE ROADS

Chairman—R. J. WIG
Bureau of Standards, Department of Commerce, Washington, D. C.

N. H. TUNNICLIFF
Civil Engineer, Davenport, Iowa.

W. A. McINTYRE
Engineer Ass'n of American Portland Cement Manufacturers, Philadelphia, Pa.

Your Committee has collated such data as were available on the expansion and contraction of concrete, especially that applicable to roadways, and begs to submit a report in which the subject is considered in the following order:

I. The cause and effect of expansion and contraction of concrete in concrete roads.

II. The application of present knowledge to the prevention of cracks in concrete road construction.

III. Suggestions for further investigation.

I—THE CAUSE AND EFFECT OF EXPANSION AND CONTRACTION OF CONCRETE IN CONCRETE ROADS

The effect of contraction may be finally evidenced by cracking and that of expansion by crushing, spalling or buckling. The engineer is interested in this subject only so far as it affects the integrity of the road. The chief causes of expansion and contraction are:

1. Changes in the temperature of the concrete.
2. Variation in the moisture content of concrete.
3. Variation in the condition and character of the sub-base.
4. Excess loading by traffic.

1. *The Effect on Expansion and Contraction of Temperature Changes in the Concrete*

It is generally considered that the variation in the temperature from season to season tending to cause a change in length, combined with unequal frictional resistance between the concrete and the sub-base, is the primary cause of cracking. The change in the length of concrete due to temperature if free to move, as determined by Bonnicau, Annals des Ponts et Chaussées, Christophe, Le Bé ton Armé, Sir A. R. Binnie, Proc. of Min. Inst., C. E., W. D. Pence, Purdue University, Professor Hallock, Columbia University, Professor Lyford, Worcester Polytechnic, and Professor Norton, ranged from .00000805 to .000004355 per degree F. per unit length, the accepted value being about .000006. Assuming a normal range of temperature of 90 degrees F. the movement which would occur without restraint is about .00054 per unit of length.

In practical work, however, several elements enter tending to modify the temperature effect. A reduction in the moisture content of concrete would cause a contraction while an increase would cause expansion, thus aiding or counteracting the effect of temperature. The friction on the sub-base in the case of a road will always reduce the movement. In some recent experiments made by Henry S. Spackman upon experimental slabs of 1:2:3 concrete 18 inches wide, 6 feet 6 inches long and 6 inches thick, on a clay sub-soil a total movement of .00017 per unit length was observed under a change in temperature of 65 degrees F. between July and November. The theoretical temperature movement for this range would be .000384 per unit of length.

Measurements made by the Bureau of Standards on a concrete road on Morris Turnpike, near New Village, N. J., covering a period from October, 1912, to October, 1913, and in Nazareth, Pa., from June to October, 1913, show that the linear change in the concrete is not in accord with the temperature change. These measurements were made by stretching an invar tape, graduated to meters, along the road spanning several slabs and reading every second meter, the figures recorded as slab changes represent changes between the points nearest the ends of the slab. Readings were recorded to hundredths of a millimeter (.00039 inches). This is illustrated in Figures 1 to 3 of the Bureau of Standards diagrams, pages 56, 57 and 58, in which the linear changes occurring in a number of slabs have been plotted together with the mean temperature, moisture and weather curves. It will be noted that curve "K", Figure 3, shows a continual shortening of a 32 foot slab. The concrete was placed June 9th and measurements started June 18th. Between the latter date and August 19th there is a considerable shortening of the slab although the temperature had increased during this period. From August 19th to September 30th there was a drop in temperature and the shortening still continued.

The measurements plotted in curve Z-3, Figure 2, were started five days after the concrete was laid. The curve indicates an elongation from November to April, when it reaches a maximum, followed by a shortening until August, when a decided shortening is evidenced and this is followed by an elongation until October.

During this period there was a mean temperature range from 16 degrees to 84 degrees F.

In curve E, Figure 1, the linear change in a 50 foot slab is plotted over the same period covered by curve Z-3, Figure 2. Measurements were started on this course the day after the concrete was laid. During the winter months there is indicated an increase in length and from April until August a decrease. Curve E, Figure 1, shows a small expansion and contraction during the first week but otherwise conforms to curve Z-3, Figure 2. The changes plotted do not represent the differences obtained from observations made upon the end reference plugs only, but are obtained by summing up the changes observed at points two meters apart throughout the length of the slab.

The only explanation which can be given for the marked contraction in the slab plotted in curve K, Figure 3, is that this slab was constructed on an old concrete road in which the cracks were sealed with cement mortar and a half inch layer of clay placed upon this base to prevent a bond being formed between the new and old concrete. These conditions prevented the new concrete from absorbing moisture from below and permitted evaporation *from the top*, thus causing a shortening of the slab. This phenomenon has *been demonstrated* by laboratory tests.

: expansion indicated by curves E, Figure 1, Z-3, Figure 2, and K, 3, from November to April, could not be due to temperature influence :refore must be due to increase in moisture content of the concrete. be noted from the precipitation curve that considerable rain fell during :er part of March and the early part of April. The contraction from o August is contrary to the condition which should result from a rise ›erature, and this can only be explained by a drying out of the concrete ıt in amount not only to overcome the expansion due to a temperature : of 20 degrees F. but also to show a substantial contraction. From to October the slab shows expansion which again can be explained ncrease in moisture content as there is no rise in temperature. It will rved that this condition prevails in a number of other curves.

e only explanation which can be offered for an expansion similar to dicated in curve E, Figure 1, is the fact that the day after the concrete id the surface was thoroughly sprinkled with water and kept wet the whole day, and there is also the possibility of temperature increase chemical action during the setting of the cement assisting expansion. ab plotted in curve E, Figure 1, together with all slabs of courses ınd C, were sprinkled more thoroughly than any of the other slabs.

ere is no data available to indicate the expansion which might be :d in green concrete due to a rise in temperature brought about by al action during setting. Several of the curves of results obtained on A, B, and C, Morris Turnpike, would indicate that this setting ıight be effective in causing expansion. Temperature measurements een taken in a number of cases, such as the Boonton Dam in New the Panama Canal Locks, the Walnut Street Bridge, Des Moines, and the Keokuk Dam, as well as in laboratories of Lehigh University 'atertown Arsenal, and the temperature increases were noted to range :7 degrees F. to 108 degrees F. in less than 18 hours after mixing. great increase in temperature as these it is believed would have some but its magnitude can only be determined by further investigation.

variation in the quality of the concrete may also cause a variation in :rmal coefficient of expansion and it will of course affect the movement takes place, as the modulus of elasticity of the concrete does change change in the quality.

ıe Effect on Expansion and Contraction of Variation in the Moisture Content of Concrete

has been definitely established that with an increase in moisture content :s an expansion of the concrete and with a decrease in the moisture t a contraction. This phenomena is apparently true for all concretes ages.

:e magnitude of this change is not definitely known but experiments by ıinger, Schumann, Tomei, Considere, Campbell, White and Gary show:

) Neat cement hardening under water expands +0.15 per cent by volume and the increased volume is approximately 0.08 per cent for a period of from 30 days to 5 years. The maximum expansion obtained at 1 year is nearly as great as at 5 years.

) Neat cement hardening in air contracts 0.25 per cent by volume in from 16 weeks to 5 years.

) Cement-sand mortars change in like manner but to a lesser degree.

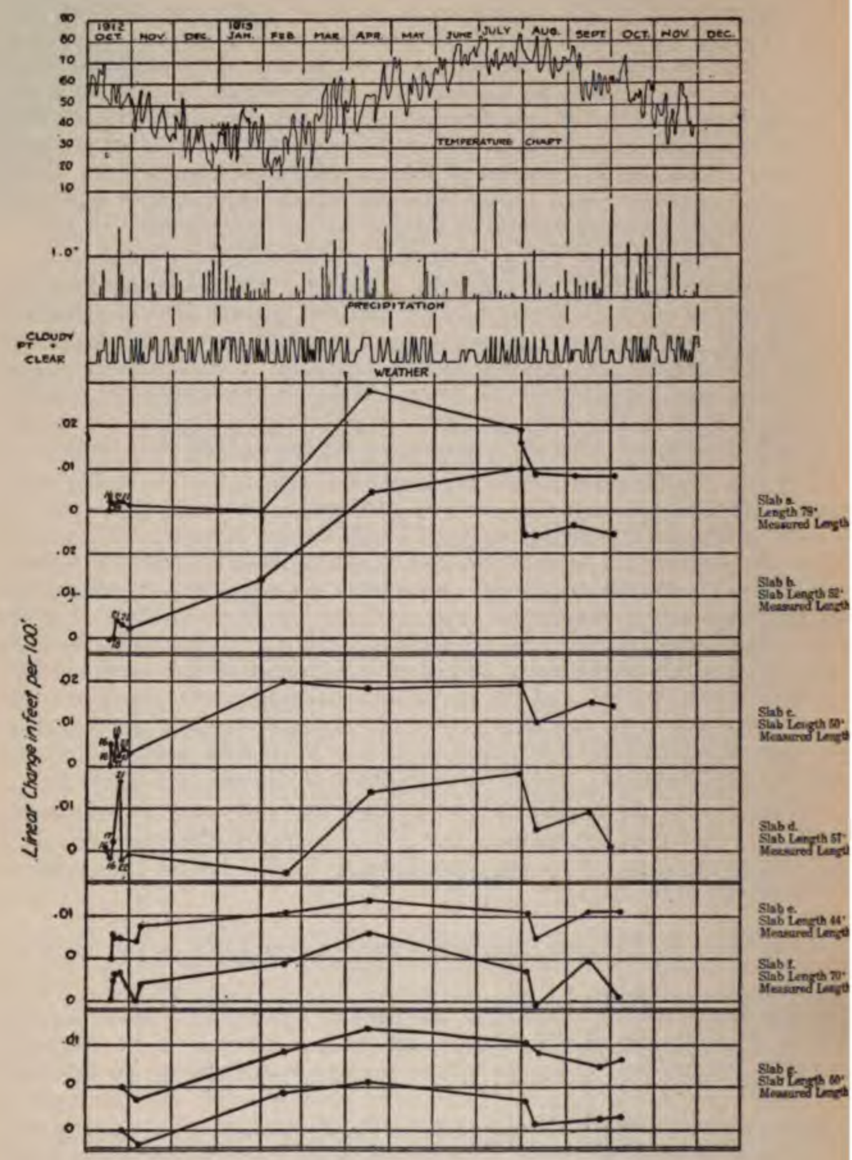


Fig. 1

The Effect on Expansion and Contraction of variations in Temperature, Moisture and Weather Changes, from measurements taken by the Bureau of Standards on the Morris Turnpike.

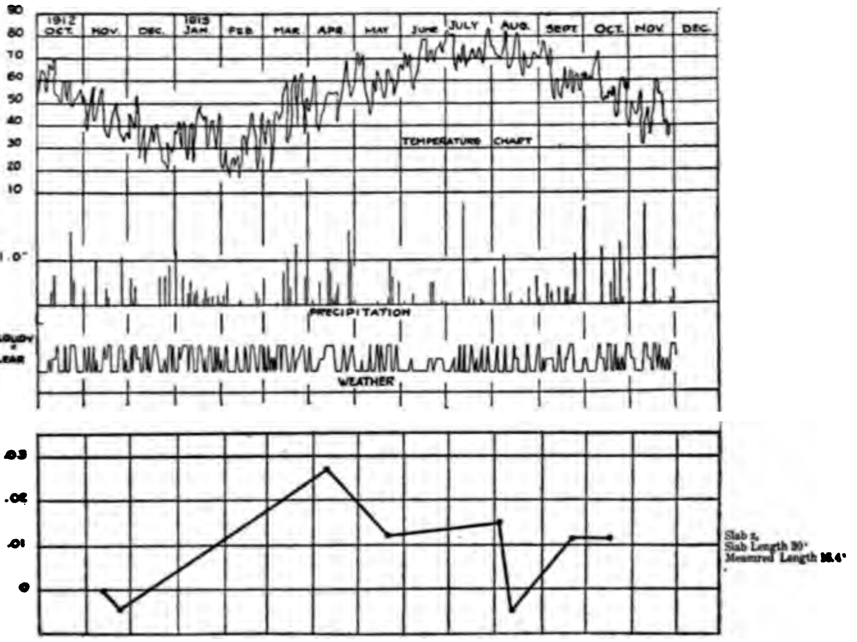


FIG. 2

The Effect on Expansion and Contraction of variations in Temperature, Moisture and Weather Changes, from measurements taken by the Bureau of Standards on the Road at Nazareth, Pennsylvania.

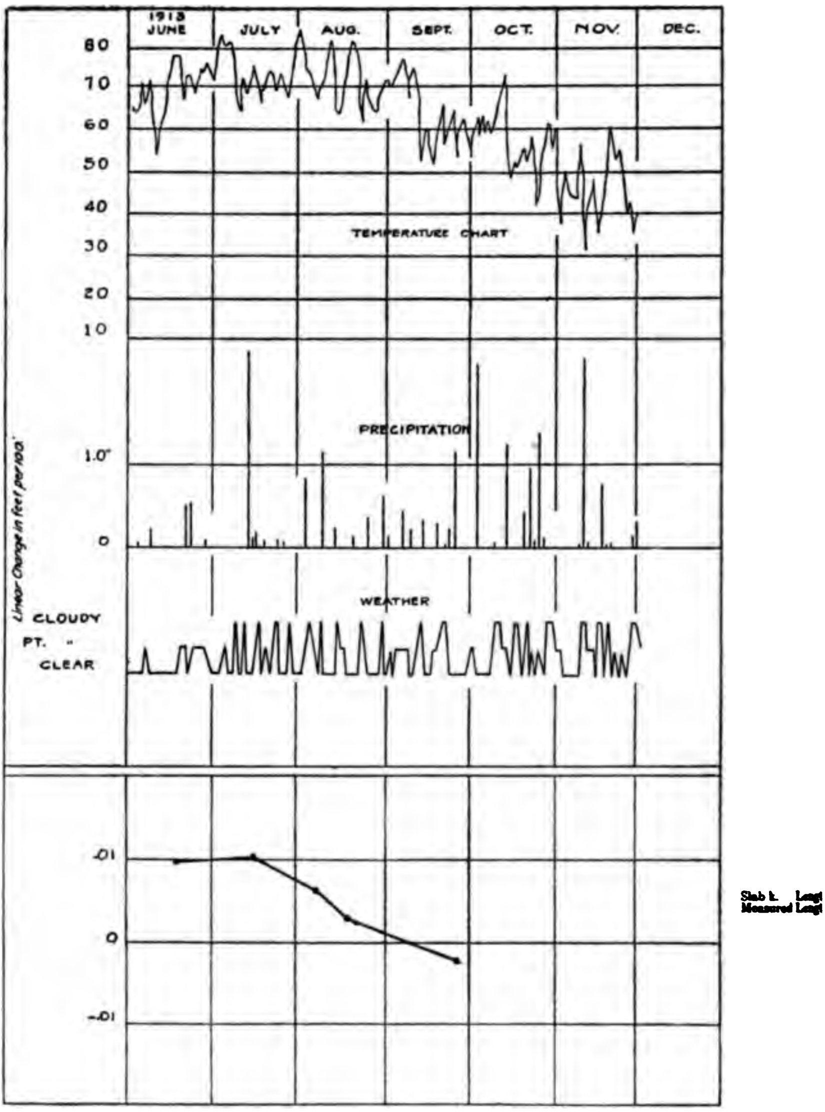


FIG. 3

The Effect on Expansion and Contraction of variations in Temperature, Moistu and Weather Changes, from measurements taken by the Bureau of Standards on a Old Concrete Road.

Experiments by the University of Michigan show the following results:

1. Neat cement hardening in air has an average unit linear contraction of

—0.00109 at 7 days
—0.00190 at 28 days
—0.00236 at 6 months
—0.00270 at 1 year
—0.00289 at 2 years
—0.00322 at 4 years

2. That neat cement that has been hardened under water for 3 years will xpand 0.0011 per unit of length and if then exposed to air for 60 days will ontract 0.0005 per unit of length less than the initial length and will therefore how a total linear contraction of 0.0016 per unit of length.

3. That neat cements under water show a linear expansion of from).0007 to 0.0015 per unit of length at the end of one year and after that a ery slight additional expansion.

4. That neat cement alternately exposed to air and water will show esults if plotted that will form a regular saw-tooth curve.

5. 1:3 mortars show linear changes in the same direction as those of ieat cement but to a lesser degree. Submerged bars show a linear expansion n the first few weeks of as much as 0.0005 per unit of length but decrease lightly after that and then expand later to a length greater than the maximum xpansion of 0.0005. Bars of 1:3 mortar in air shrink in length to an verage of 0.0008 per unit of length within 3 months.

6. Experiments with sections of a top coat of a cement walk which had een laid 20 years showed that it expanded when immersed 0.0005 per unit f length and contracted the same amount when again dried.

7. Experiments with a section of stucco two years old, from a brick iouse, showed a linear expansion when immersed of 0.0008 per unit of ength in 4 days, and a return to its original volume when dried.

8. Experiments with a section of cement walk in which a sample of oth the top course and base were bound together showed that upon immer-ion the base reached its maximum expansion in 15 minutes while it took the op coat 3 days to reach the same expansion.

"This is interesting partly because of the evidence of alternate bending tress in the concrete due to the more rapid expansion of the lower layer and artly because of the ultimate agreement in expansion of the top and bottom ortion." This cement sidewalk was in good condition after 20 years' service.

A. T. Goldbeck of the U. S. Office of Public Roads reports experiments n this subject as follows:

"The specimens used were 8 inches in cross sections and 5 feet long. They were molded as columns so that one end would be absolutely free to xpand and contract, due to any cause. Different proportions by volume and lifferent consistencies were used. The specimens of very dry consistency required hard tamping to consolidate the concrete in the mold, while those of wet consistency were made by simply puddling the mixture into place. The amount of water used for the dry mixtures was 8.5 per cent of the weight of the dry materials. For the wet mixtures from 10 to 12 per cent was used. The materials entering the concrete mixtures were Portland cement, bank sand and 3/4 inch crusher run gneiss.

"The initial readings on all specimens were taken as soon as the concrete had hardened sufficiently to remove the molds.

"The specimens which were allowed to dry out immediately after molding began to shrink almost from the day they were made, although the very wet mixtures for the first few days showed a tendency toward slight expansion, amounting to about .00005 inch in the 5 feet length of specimen.

"The rate of shrinkage of the dry mixtures is very slightly higher at earlier periods than that of the wet mixtures. There is, however, very little difference between the shrinkage of the different mixtures except that the contraction of the wet specimens is delayed. The unit contraction of the oldest specimen of very dry mixture is 0.00052 at the age of 3 months, and the rate of contraction after this age is very small. The results further indicate that the approximate contraction of concrete of the proportions and consistencies ordinarily used is 0.0005 per unit of length at the age of 3 months.

"The specimens which were kept moist showed expansion as long as they were wet. However, as soon as they dried out contraction began. The indications are that dry mixtures are more sensitive to expansion upon being moistened than are the wet mixtures. The amount of expansion is, however, quite small, reaching as a maximum approximately 0.0001 per unit of length. It will be seen that the rate of shrinkage of the moistened specimens, when allowed to dry out, approximates that of the air-cured specimens, so that one of the effects of moistening the concrete for the first few days is to delay the shrinkage. It is probable that ultimately the amount of contraction of both air and water cured specimens will be the same. A specimen, which was kept in a moistened condition continuously, although not expanding progressively, showed expansion up to the last measurement."

The results of experiments made by the Bureau of Standards show as follows:

RESULTS OF TESTS OF LINEAR EXPANSION OF NEAT CEMENT STORED IN VARIOUS MANNERS

Test piece (1 inch by 1 inch by 13 inches) neat cement prisms.

Number of Cements	Manner of Storing	Age of Test Piece	Change in Length Per Unit of Original Length
6	In Water	30 days	+0.00095
8	In Water	30 to 60 days	+0.00105
4	In Water	120 days	+0.00113
20	In Water	6 to 9 months	+0.00152
6	In Air	30 days	−0.00150
15	In Air	30 to 60 days	−0.00167
4	In Air	120 days	−0.00211
40	In Air	6 to 9 months	−0.00285

It was noted that prisms which had been stored in air when placed in water at practically any age began expanding, the expansion proceeding in manner similar to prism placed directly in water after molding. Similarly prisms stored in water contracted when removed and kept in air.

Note:—The original reading was taken on removal from damp closet 24 ours after molding.

Investigations have not been extensive enough to form final conclusions n the effect of moisture on expansion and contraction, but the following tatements may be made which are in part applicable to concrete roads.

All of the tests quoted above show expansion of neat cement and of ortar and concrete when the samples are hardened under water. The esults show the extent of this expansion to be greater with neat cement and o decrease where the addition of sand or coarse aggregate is made.

These tests also show that neat cement mortar and concrete will contract when hardened in air and that the contraction of neat cement is the greater, while that of mortar or concrete varies with the amount of sand and coarse ggregate used in the mixture.

They show that to an age of 20 years and possibly for all time, these hanges may be looked for in concrete.

They show that the condition which would provide for a decrease in moisture content when the temperature increases and an increase in the moisture content when the temperature decreases would be an ideal one.

All these tests indicate that the effect of moisture content is very much greater than the effect of temperature change and may be sufficient to cause a stress in the concrete opposite to that which would be caused by a normal emperature change.

A variation in the quality of the concrete will cause a variation in the endency to expand and contract with change in moisture content, as dense mixtures absorb water less rapidly than porous mixtures.

If concrete of two qualities in a road were exposed to an equal amount of moisture for a short period, the more porous of the two would have a tendency to expand the most and would have the less strength to resist the stresses set up. Assuming only a slight change in temperature and that the frictional resistance on the sub-base was uniform, the more porous concrete would have to move the greater distance, higher tensile stresses would be set up upon drying out and it would be the more liable to crack.

If one course work concrete of two qualities in the same slab in a road were similarly exposed, the same tendency would be exhibited and this may, in certain cases, be sufficient to cause a separation of the two concretes or may cause a number of small cracks.

If in two course work the base is of a more porous concrete than the top, the tendency would be to have unequal expansion and contraction in the slab, due to different moisture content in these mixtures causing the bottom to move more than the top or vice versa. Also if the concrete road is subject to a heavy rain for a considerable length of time the bottom will be exposed to moisture in the ground for a longer time than the surface and the surface will be more or less dried due to exposure to the sun and consequently the top would tend to contract while the bottom would still be expanding.

3. *The Effect on Expansion and Contraction of Variation in the Condition and the Character of the Sub-base*

The condition and character of the sub-base would affect the support of the road; the amount of moisture transmitted to and from the concrete; the action of frost; and the friction on the bottom of the slab. All of these factors affect the expansion and contraction of the concrete.

If the slab of concrete is not uniformly supported, sections may be stressed, causing tension or compression in an amount sufficient to exceed the strength of the concrete, resulting in cracking. A condition illustrating this point may be found where a concrete road is built over an old stone road bed of less width than that of the concrete slab. The foundation at the sides, which is not so compact as that at the center, will settle more, causing expansion in the surface of the concrete slab possibly sufficient to cause a crack. While there is no experimental data available definitely establishing this point, it is believed the longitudinal cracks in Course "C", New Village, N. J., may be thus accounted for.

The amount of moisture transmitted to and from the concrete through the sub-base depends upon the porosity and density of the material in the sub-base. It is believed that this fact explains the difference in the action of slabs plotted in curves Figure 3, K, and Figure 2, Z-3, and referred to under "The Effect on Expansion and Contraction of Temperature Changes in the Concrete." The action of frost can only occur in a sub-base containing moisture in localities in which the temperature gets sufficiently low to freeze to a depth of the sub-base. This action is therefore dependent upon the porosity and capillarity of the sub-base material and the depth of the water table below the concrete. The effect of freezing and thawing is to place the slab in stress which may cause cracking.

From observations made it would appear that the cracks usually occur during a thaw rather than during a frost and this may be explained by the fact that the heat may be transmitted more rapidly through the shoulders than through the center of the road, causing unequal settlement. If the heaving action of frost does cause cracking it is usually due to raising the edge of the road, which will probably crack the lower side, which may not be apparent until the slab returns to its original position when the crack will appear on the upper surface.

The friction on the bottom of the slab is dependent upon the condition of the sub-base. The effect of this friction is to restrain movement in the concrete; therefore the tendency to volumetric change due to change in moisture content and thermal change would be restrained. This restraint would set up stresses in the concrete probably proportional to the restraint. This is shown in the experiments made by Mr. Spackman. Referring to these results and considering only the effect of temperature there should have been a theoretical movement of 0.000384 per unit length and yet only a movement of 0.00017 per unit length was obtained. An inspection of the movements recorded in Figures 1 to 3 also show that the movements were not in accordance with theoretical requirements. The change in moisture content is not known and most probably had something to do with the discrepancies. Thus the actual movement observed by Mr. Spackman due to temperature may have been greater or less than that indicated by the figures.

The longitudinal grade of the road would affect the friction on the bottom of the slab. On a 5.2 per cent grade on Morris Turnpike a slab 30 feet long was observed to have moved down hill, the joint at the upper end of the slab being decidedly open while the lower end of the slab slid upward on the adjoining slab. The joint in this case was not perpendicular to the slab. Measurements also substantiate the above conditions. This sliding may have been assisted by changes in the thermal and moisture content of the concrete.

4. *The Effect of Traffic on Expansion and Contraction*

The expansion and contraction of concrete is probably the least affected y loads brought upon the road by traffic than by any of the above mentioned auses. The effect is, however, not to be neglected, particularly when it acts ı conjunction with an uneven settlement of the sub-base, similar to that eretofore mentioned of a slab being placed over an old stone road of less ridth than that of the concrete. The result would be cantilever or beam ction and the consequent throwing into tension the top of the slab, which ıay cause cracking.

I—APPLICATION OF PRESENT KNOWLEDGE TO THE PREVENTION OF CRACKS IN CONCRETE IN CONCRETE ROADS

There are a great many factors affecting the expansion and contraction f concrete in concrete roads, and in order to present the available data in a lear and concise form your Committee has prepared a list of questions coverıg conditions which might arise in the mind of the engineer as influencing xpansion and contraction. These questions have been answered in accordance rith the available data.

A—Cracks

Is it possible to prevent all cracking of concrete in roads by a proper pplication of engineering principles?

Your Committee believes that with a proper understanding of the physical henomena affecting the expansion and contraction of concrete in roadways, racking can be eliminated.

(1) When do cracks usually occur?

Longitudinal cracks usually do not occur until seasonal changes.

Transverse cracks may occur at any time but the majority should occur uring the first dry season.

(2) What is the cause of transverse cracks?

Transverse cracks are probably due to a favorable combination of moisture ontent in the concrete and atmospheric temperature conditions, together with restraint induced by the condition of the sub-grade.

They may, however, be caused by an unstable foundation.

(3) What is the cause of longitudinal cracks?

Longitudinal cracks are probably in the majority of cases caused by an nstable condition of the sub-base, although they may be caused by a favorable ombination of moisture content in the concrete and atmospheric temperature onditions together with a restraint induced by the condition of the sub-grade. The latter is particularly effective if the sub-base is crowned.

(4) What is the cause of diagonal cracks?

Diagonal cracks are probably most commonly caused by a combination of oisture content in the concrete and atmospheric temperature together with restraint induced by the condition of the sub-base. In rare cases they may e caused by the above combination and longitudinal restraint along one side hen abutting a rough structure.

B—Effect of Quality on Cracking

(5) What mixture of concrete should be used?

The best mixture is the one which is the most dense and which will reduce to a minimum the absorption of moisture, but it should also have a strength of at least 1500 pounds per square inch at the end of 28 days.

(6) How should the concrete be mixed?

It should be mixed in such a way as to give a product of uniform quality.

(7) How should the concrete be placed?

It should be placed in such a manner as to give a uniform quality of concrete in place and to prevent loss of water.

(8) How should the sub-base be treated before placing the concrete?

The sub-base should in all cases be thoroughly wet so as to prevent absorption of moisture from the concrete and thus cause a rapid drying out of the concrete.

(9) How should the concrete be cured?

The concrete should be cured in such a way that it will retain its own moisture and receive sufficient additional moisture until it is strong enough to resist the shrinkage stresses induced by drying out.

C—Relation of Slab Length to Cracking

(10) What is the maximum permissible length of plain concrete slabs?

The maximum permissible length of slabs, of similar design, on a firm foundation, on a light or flat grade will vary with the climatic conditions. In localities where there is little rainfall, as in Arizona or the San Joaquin Valley in California, the slab length probably should not exceed 25 feet. This length has been determined by an analysis of a report by A. B. Fletcher, State Highway Engineer of California, on the cracking of a monolithic road, together with a knowledge of the results of measurements obtained by the Bureau of Standards.

In localities where the rainfall is intermittent and the ground water rises in cool seasons and lowers in warm seasons, similar to conditions which obtain east of the Mississippi River, the slab may vary in length from 30 feet to a continuous slab. While the 30 foot slab may be regarded as a minimum length, from economical considerations, the results of experiments indicate that cracks are quite likely to occur under certain conditions even in this length. In many cases it will be observed that even in short slabs only slight motion has occurred at the ends, although there has been considerable motion within the slab, which has been absorbed at points of restraint. Other factors affecting the length of the slab are discussed in other questions.

(11) Does the length of the slab affect longitudinal cracking?

The data available to the Committee would indicate that the length of the slab for the same sub-soil conditions does not affect longitudinal cracking. It is, however, interesting to note that in a report by A. N. Johnson, State Highway Engineer of Illinois, is to be found a statement that in roads constructed by him in 1912 with a total length of 2.3 miles he finds 9.1 slabs per mile, cracked longitudinally, transverse joints being spaced from fifty to *one hundred feet* apart, on roads sixteen to eighteen feet in width. A report

TABLE No. 1

Observations Made During August and September, 1913, on Cracking of Wayne County, Michigan, Concrete Roads, by F. F. Rogers, State Highway Commissioner of Michigan, and J. J. Cox of the University of Michigan.

Name of Road	Number of 25 ft. Sections	Width in feet and inches	Average thickness	Mix	Year Built	Soil Built on	Traffic Count 24 hr. average 1 week	Number of Cracked Slabs						
								Longitudinal cracks	Per cent	Transverse cracks	Per cent	Diagonal cracks	Per cent	Total number cracks
Woodw'd Av.	209	18	6½	1:2½:5 1:2 :3	1909	Clay lm.	2160	80	38.2	32	15.4	2	0.9	114
Woodw'd Av.	252	18	6½	1:2½:5 1:2 :3	1910	Sandlm.	....	29	11.5	22	8.7	6	2.4	57
Gratiot Av.	326	16	7	1:1½:3	1911	Clay lm.	507	11	3.4	10	3.0	3	1.0	24
Grand R. Av.	61	18	6½	1:2½:5 1:2 :3	1909	Clay lm.	1064	11	18.0	2	3.3	1	1.7	14
Grand R. Av.	308	16	6½	1:2½:5 1:2 :3	1910	Clay lm.	....	59	19.1	20	6.5	29	9.5	108
Grand R. Av.	515	16	7	1:1½:3	1911	Sandlm.	....	13	2.5	26	5.0	3	0.7	42
Grand R. Av.	1208	16	7	1:1½:3	1912	Sandlm.	352	70	5.7	44	3.8	13	1.0	127
Michigan Av.	481	17'8"	6½	1:2 :4	1910	Clay lm.	1009	219	45.5	48	10.0	23	4.8	290
Michigan Av.	1570	18	7	1:1½:3	1911	Sandlm.	....	219	13.9	80	5.1	42	2.7	341
River Road..	149	15	6½	1:2 :4	1910	Clay	538	49	32.8	5	3.4	6	4.0	60
River Road..	434	15	7	1:1½:3	1911	Clay	....	165	38.0	17	4.0	13	3.0	195
River Road..	213	15	7	1:1½:3	1912	Clay	....	14	6.6	8	3.7	4	1.9	26
River Road..	208	15	7	1:1½:3	1912	Clay	....	17	8.2	9	4.3	0	0.0	26
Fort St. Road	450	12	7	1:1½:3	1912	Clay	....	0	0.0	19	4.2	9	2.0	28

of F. F. Rogers, State Highway Commissioner of Michigan, on the Wayne County Roads, shows that on roads constructed in 1912 with a total of 9.6 miles, 9.5 slabs per mile cracked longitudinally, transverse joints being spaced twenty-five feet apart on roads fifteen and sixteen feet in width. See table No. 1.

(12) Is it necessary to vary the length of the slab for concretes of different qualities?

The length of slab should vary with the quality of the concrete. In a short time a denser concrete will absorb less moisture and consequently will have less tendency to move; it will also have greater strength to resist stresses induced by restraint of the sub-base. A dense concrete is particularly of value where subjected to intermittent wetting and drying. In a dry climate where plenty of water is not available for curing, the slab length should not exceed twenty feet.

(13) Should the length of the slab be the same for all sub-soil conditions?

The length of the slab should not be the same for all sub-soil conditions. If the sub-soil is of unstable material the length of the slab must be shorter than for a condition in which the sub-soil is stable.

(14) Is it necessary to vary the length of the slab with a variation in the character of the sub-base?

If there is a distinct variation along the length of the road in the materials of which the sub-base is constructed a joint should be placed where the change takes place. This is necessary because of the change in the frictional restraint offered by different materials and also because of the difference in the porosity which changes the moisture conditions.

(15) Is it necessary to vary the length of the slab with a variation in the condition of the sub-grade?

The length of the slab should vary with the condition of the sub-grade. If the sub-grade could be made very smooth so that a more or less uniform frictional resistance would be obtained throughout the length of the slab, it would perhaps be the most desirable condition, but as this is not obtainable it is believed that a more or less uniformly rough sub-grade is preferable to a so-called "smooth" sub-grade. This is explained by the fact that the rough sub-grade will make each small section in the slab care for its proportionate share of the stress induced by frictional restraint, while if the sub-grade is so-called "smooth" there will be rough places in it at intervals which will place upon certain sections undue stresses, which therefore will be more liable to cause cracks. If there is any decided change along the length of the road in the condition of smoothness of the sub-grade a joint should be placed at the point where this change occurs.

If the sub-grade is so-called "smooth" on a steep grade, the permissible length of slab would not be as long as on a light grade, there being a tendency to slide down hill and thus add additional stress to that imposed by moisture and temperate change.

(16) Is the length of the slab dependent upon the grade of the road?

If the grade is steep the slab should be shorter in length than that used on a flat grade. A joint should be placed at all decided changes in grade.

(17) Is it necessary to vary the length of the slab with climatic conditions?

See reply to Question 10.

(18) Is it necessary to vary the length of the slab with the season when constructed?

It would appear that the slabs could be made longer if constructed during the fall or winter, in localities where not subjected to freezing, than if constructed in either the spring or summer, although there is not sufficient data available to determine whether this would permit of an appreciable change in length.

Conditions indicate that concrete laid in the fall is probably not subjected to stress as much during the first few months, since the tendency to increase in length due to moisture is counteracted by the tendency to decrease in length due to temperature.

(19) Is it necessary to vary the length of the slab if a bituminous carpet covering is applied?

The experimental results indicate that there was greater movement of the concrete covered with a bituminous carpet than with concrete uncovered. If, upon further investigation, this condition is found to hold true the slab length would probably have to be varied. The reason for the greater movement noted is probably to be explained by the fact that a dark surface absorbs more sun heat and the bituminous coating holds for a longer period any moisture which gets beneath it.

(20) May the length of the slab be made greater for a greater thickness of slab?

The length of the slab may be made greater for a greater thickness of slab. The increased friction caused by increased weight is proportionately less than the increased ability of the concrete to resist stress. Sufficient data are not available to give a relative figure.

(21) Should the length of slab be different for different traffic conditions?

It is not believed that traffic need be considered in determining the length of the slab.

(22) Does the type of joint affect the length of slab?

There would tend to be a greater movement in a wide or elastic joint than in a narrow or unelastic one and since cracking occurs during contraction there would be less movement with a tight joint; a tight joint therefore would permit of a longer slab. It is not known, however, that this factor is sufficiently appreciable to be considered in determining the length of the slab.

D—Relation of Cross Section of Slab to Cracking

(23) What is the relative likelihood of longitudinal cracking in slabs of different design but of uniform cross section?

A concrete road laid on a crowned sub-base would be the most liable to crack longitudinally and on a dished sub-base the least liable to crack. The resistance offered to contraction of a slab with a crowned sub-base is greater than that offered by either a dished or flat sub-base, because the concrete must move against the effect of gravity. With the dished sub-base the concrete contracts with the effect of gravity and therefore is stressed the least.

(24) What is the relative likelihood of longitudinal cracking in slabs of different design but of non-uniform cross section?

The cross section having the greatest thickness at the center with a dished sub-base would offer the greatest resistance to longitudinal cracking; the cross section having the least thickness at the center with a crowned sub-base would offer the least resistance to longitudinal cracking.

(25) Does the width of the slab affect transverse cracking?

It is not believed that transverse cracks are in any way affected by the width of the slab. The data available to the committee would indicate that the width of the slab for the same sub-soil conditions does not affect transverse cracking.

(26) Is it necessary to vary the design of the cross section of the slab with the relative position of the longitudinal drain?

The slab should have its greatest thickness at the center no matter where the longitudinal drain is placed.

(27) Is it necessary to vary the design of the cross section of the slab with sub-soil conditions?

Over an unstable sub-soil the slab should be made of greater thickness throughout the width than over a stable sub-soil, with the greatest thickness at the center.

(28) Is it necessary to vary the design of the cross section of a slab with the condition of the sub-grade?

No.

(29) What is the preferable design of cross sections for different climatic conditions?

The dished is the preferable design under all climatic conditions, especially in arid regions.

(30) Is it necessary to vary the cross section of a slab with the season when constructed?

The dished sub-base is the preferable cross section for all seasons and especially so if the concrete is laid during the dry season.

(31) What should be the relation between the thickness at the center and the width of the concrete road?

The wider the road the thicker should be the slab.

(32) Is it necessary to vary the design of the cross section with the length of the slab?

No.

(33) Is it necessary to vary the design of the cross section with the traffic conditions?

A concrete road which must withstand heavy and concentrated traffic must be made thicker than for light traffic.

E—The Value of Reinforcement in Preventing Cracking

(34) When should reinforcement be used?

Reinforcement will be of value

- (a) When the foundations are uncertain;
- (b) In regions where there is little rainfall and long or wide slabs are desired;

(c) In regions where there is insufficient water for curing;
(d) When it is necessary to have a thin slab;
(e) When a decided change in grade occurs;
(f) When the movement of the concrete is restrained at street intersections or on curves, if joints cannot be placed properly;
(g) When the width of the slab is greater than 25 feet;
(h) When it is necessary to crown the sub-grade and the slab can not be made thicker at the crown than at the sides.

(35) What type of reinforcement should be used?

Only fabricated steel should be used and that form which will give the reatest distribution.

(36) How much reinforcement should be used?

The quantity of reinforcement can only be determined by an analysis of he conditions affecting each specific case.

(37) What is the proper position of the reinforcement in the slab?

If uncertain sub-soil conditions tend to cause a settlement on the sides f the road, which is the most common condition, the reinforcement should e near the top. If settlement is apt to occur within the center of the slab he reinforcement should be placed near the bottom, and where the whole f the sub-base is uncertain the reinforcement should be placed near both top nd bottom.

Reinforcement to resist stresses due to temperature and moisture changes hould be placed near the bottom of the slab. The stresses set up by a change n temperature are insignificant, except in arid regions, compared with those et up by moisture changes, and ordinarily reinforcement to provide for temerature stresses is unnecessary.

(38) What is the maximum permissible length of reinforced slab?

Your Committee can give no definite answer to this question. The slab ength may be anywhere from 20 feet to continuous depending upon the nany elements entering into the problem.

(39) What is the maximum permissible width of reinforced slab?

The widest pavement without cracks within our knowledge is 40 feet. t is probable wider pavement can be constructed.

(40) May the slab be made thinner if reinforcement is used?

It would appear that if properly designed a thinner slab may be used if einforced. Definite information, however, is lacking to exactly determine his fact.

(41) Do the conditions of construction affecting cracking apply to plain oncrete slabs as well as to reinforced slabs?

Yes.

F—The Effect of Joints on Cracking

(42) What is the purpose of joints?

The purpose of joints is to relieve the stress which might be induced by volumetric change in the concrete caused by change in moisture content or emperatures and to care for unstable foundation conditions. The Committee as no evidence *of the failure of* slabs in concrete roads due to buckling,

crushing or spalling and therefore consider the joint as primarily for the purpose of taking care of contraction.

(43) What is the objection to the construction of a concrete road without joints?

If a concrete road is constructed without considering the affecting factors, with the idea that nature will provide cracks, it will crack, but before doing so it will cause a weakening of the concrete for some distance on each side, which may result in a partial disintegration of the road. This is evidenced by short forked cracks appearing running off from the main crack. The cracks thus formed will gradually lengthen with time and will not only be irregular in alignment but they will not be vertical.

(44) Does the width of the joint affect cracking?

The width of the joint controls the longitudinal movement of the slab. A greater width will allow of greater movement, consequently the slab will be more liable to crack upon contracting.

(45) What is the proper width of joint?

A joint should be constructed as a contraction joint with little or no room provided for expansion, as all stresses in the concrete caused by expansion are compressive and may be absorbed by the concrete; later, upon contraction there will be little movement and therefore only small tensile stresses will be induced and there will be less liability of cracking.

(46) Should the width of the joint vary with the length of the slab?

No. Experimental results show that only the movements occurring near the ends of the slab are usually transmitted to the joints.

(47) What is the effect of the filler used?

A filler should not be too elastic to comply with the conditions set forth in answer to Question 44.

(48) What should be the position of the joint relative to the length of the road?

There are no available data to show the difference in effect of diagonal and square joints on expansion and contraction. Any joint, however, should be perpendicular so as to give proper bearing between adjoining slabs when they expand.

(49) Is it necessary to provide a longitudinal joint between road and adjoining structure?

It is if the adjoining structure is rough and will cause longitudinal restraint or if the abutting structure will not offer sufficient resistance to prevent being pushed out of place.

(50) Should joints be placed at street intersections and on curves in a country highway?

Joints should be placed at street intersections and at sharp curves so as to allow of free movement, wherever the concrete is restrained.

G—The Effect of Character and Condition of Sub-base on Cracking

(51) Is it desirable to have the sub-grade smooth or rough?

A rough sub-grade is preferable since a very smooth sub-grade is impracticable to construct. (See reply to Question 15.)

(52) Is it desirable to have the sub-base impervious?

The sub-base should be very dense but not entirely impervious. Where a rich mixture is used in the construction of a road it would tend to dry out unduly, causing excessive contraction. If a smooth sub-grade could be provided so that the friction would be reduced to a minimum it might be desirable to have an impervious sub-base, but this condition is very difficult to obtain.

(53) Is it desirable to have the sub-base thoroughly compacted?

It is desirable to have the sub-base uniformly and thoroughly compacted so as to prevent uneven settlement.

(54) Is it desirable to have the sub-base flat, curved or dished?

The sub-base should be dished.

(55) Is it desirable to have the sub-grade roughened on a steep grade?

It would be desirable to have the sub-grade roughened on a steep longitudinal grade.

III—SUGGESTIONS FOR FURTHER INVESTIGATION

In collating this report your Committee found a lack of reliable information necessary to a complete analysis of this subject and would therefore suggest the following problems for investigation:

(1) The determination of the friction of a concrete slab on different materials and under different conditions of the sub-base.

(2) A more accurate determination of the modulus of elasticity of concrete in tension and compression.

(3) The determination of the variation in the coefficient of expansion of concrete when under stress.

(4) The determination of the expansion of green concrete due to the chemical action of the cement during setting.

(5) A more accurate determination of the coefficient of expansion of different mixtures of concrete.

(6) The determination of the effect of change of moisture content in concrete when under stress.

(7) The determination of the bond between steel reinforcement and concrete when the concrete expands or contracts due to change in moisture content.

(8) The determination of the bond between steel reinforcement and concrete when the concrete expands or contracts due to change in temperature.

(9) The determination of the absorption of heat by concrete uncovered and covered with a bituminous carpet.

(10) The determination of the effect of continual alternate expansion and contraction of unrestrained and restrained concrete.

(11) The determination of the permanent set resulting in wet and dry concrete under various tensile and compressive stresses.

In conclusion, your Committee believes that it has been fully established that the change in moisture content of the concrete is of much greater moment than the change in temperature under normal exposure; and that a proper combination of change in temperature, change in moisture content and friction have *made possible* the construction of long slabs which have

remained free from cracks; while under an unfavorable combination of these factors which is to be found in certain localities, long slabs have invariably cracked. With a proper understanding of the physical phenomena which are recommended for investigation and with a proper application of engineering principles by competent highway engineers, it is believed by your Committee that all expansion and contraction of concrete in roads can be so controlled as to permanently avoid cracking.

DISCUSSION

Mr. Wig:—The report is divided into three main parts. The first part takes up the causes of expansion of concrete roads; the second covers the application of present knowledge to the prevention of cracks in concrete roads; and the third contains suggestions for further investigation.

It is necessary that we properly design concrete roads to insure freedom from cracks. There are a great many factors affecting the expansion and contraction of concrete roads and the committee has considered these factors in accordance with the available data.

Some points in the report are of exceptional importance. The question, "Should the length of the slab be the same for all sub-soil conditions," is of special importance. Your committee believes that the length of the slab should not be the same for all sub-soil conditions. If the sub-soil is of an unstable character, the length of the slab should be shorter than under a condition in which the sub-soil is stable.

The reply of the committee to the question, "Is it necessary to vary the length of the slab with a variation in the condition of the sub-grade," is unique in that it suggests a change in present practice. Observations upon the points in question were made on Morris Turnpike in New Village, New Jersey, where the slab on a grade of about 5 per cent slid a considerable distance.

Relative to the question, "Is it necessary to vary the length of the slab with climatic conditions," the committee wishes to call attention to what may seem a very unusual condition, namely: That we get the maximum contraction in a concrete road when we get our highest temperature, during August and the summer months. It seems that concrete has its maximum expansion in the road during April, when we have the greatest amount of moisture. The concrete expands from August to April and contracts from April to August, the maximum contraction being at the highest temperature, indicating that the change due to moisture conditions is very much greater than the change due to variations of temperature.

Relative to the type of reinforcement to be used, the committee is of the opinion that there are a good many reasons why rods should not be used. Rods are of very little value. Only fabricated steel is recommended.

The width of joint in a pavement is another question of importance. Joints should be constructed as contraction joints and should provide little or no room for expansion. There is evidence that the movement in a 30-foot slab is often taken up before the joints are reached and the joints may not move at all. This suggests a change from common practice.

Mr. Spackman:—As indicated by the Report of Committee I, the change in volume of hardened concrete, through variation in temperature or water content, has been subject to considerable investigation. The expansion and

contraction due to temperature changes has been recognized and studied for a number of years and a working coefficient for temperature changes developed. The recognition of the effect of the variation in moisture content on the volume of concrete is of a more recent date, but sufficient work has been done to demonstrate that hardened concrete follows the same general law of expansion and contraction through changes in moisture content as wood, but as yet we have not sufficient data to calculate the extent of the movement under varying conditions of moisture content.

It is not generally recognized, however, that concrete, before set or hardening takes place, is subject to marked shrinkage through reduction in moisture content. When we consider that during the first 24 hours, concrete has little or no strength, that its modulus of elasticity is nil and that the cohesion is small, it is evident that slight shrinkage must result in the formation of cracks, which, even though they be so small as to be scarcely visible to the eye, are a source of weakness. Such being the case, the importance of preventing shrinkage, during the period prior to hardening, becomes evident. The tendency to such shrinkage is partially indicated by Figures 4, 5 and 6 which throw some light on the subject. In each of these figures, the solid line shows the average expansion and contraction obtained from two or more test pieces made from 1 part cement to 3 parts gravel under the different conditions of exposure indicated. A marked contraction is shown by the test pieces at the 24 hour period from the original length of the specimen as ascertained by measurements made 4 hours after casting. When it is recognized that test pieces were cast in tight wooden molds, offering little opportunity for escape of the surplus water, and that the molds were thoroughly soaked and oiled to prevent absorption, that the test pieces were largely protected from evaporation and that the mortar was a lean one, being 1 part cement and 3 parts sand, it becomes evident that when concrete made from a mortar of 1 part cement and 1½ parts sand is placed in actual road construction with opportunity for the water to flow off or be sucked up by the subgrade, that much greater contraction is to be expected. This cannot but result in the forming of either more or less widely separated cracks of considerable size, or numerous small ones which, while not so noticeable, form lines of weakness, breaking the continuity of the slab and reducing the resistance to future stress.

The curves of Figures 4, 5 and 6 were plotted from the direct reading of the micrometer and indicate the contraction or expansion due to variation in moisture content in the test pieces; the variation due to temperature changes being practically equalized by bringing the micrometer as closely as possible to the temperature of the specimen measured.

Figure 7 shows the contraction and expansion of test pieces exposed out of doors due to the combined effects of variation in moisture content and temperature; the original measurements being corrected for the effect of temperature change on the length of the steel micrometer bar.

It is reasonable to suppose that until setting action begins, the shrinkage of cement mortars, due to drying out, will be found to follow the same general laws as govern the shrinkage of clays. If this is so, the sand particles and the cement particles are surrounded on all sides by a film of water, while small pools or drops fill the pores between the grains. When water is added in excess of the amount required to fill the voids, the mortar will not hold its form, but will flow. Afterward when it comes to rest, a portion of the water is forced from the mass through settlement and flows off by gravity. A

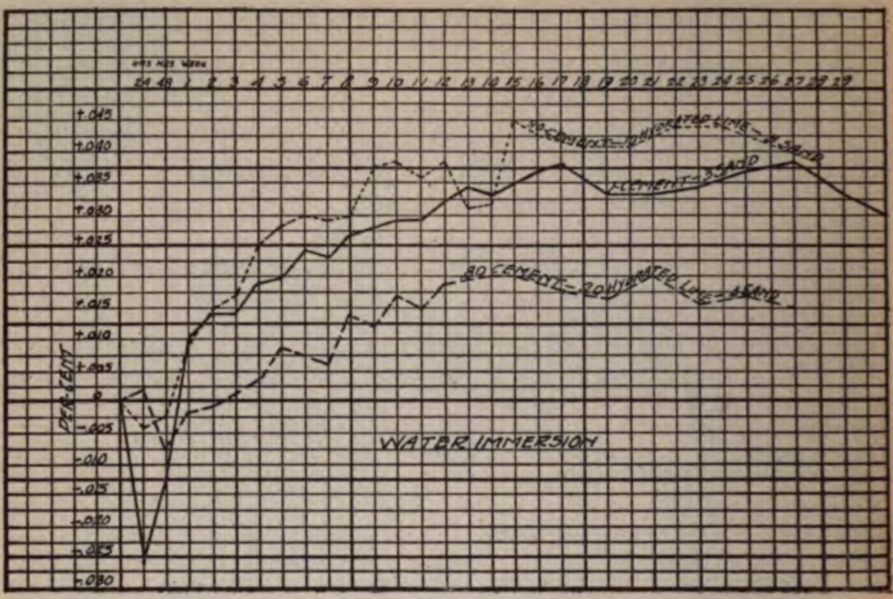


FIG. 4

The Effect on Expansion and Contraction in Test Pieces due to Variation in Moisture Content.

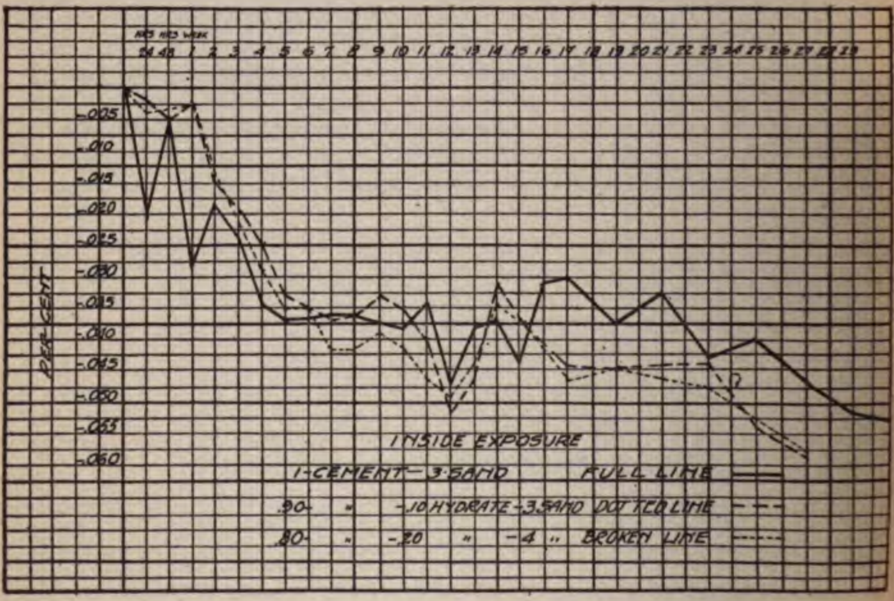


FIG. 5

The Effect on Expansion and Contraction in Test Pieces due to Variation in Moisture *Content.*

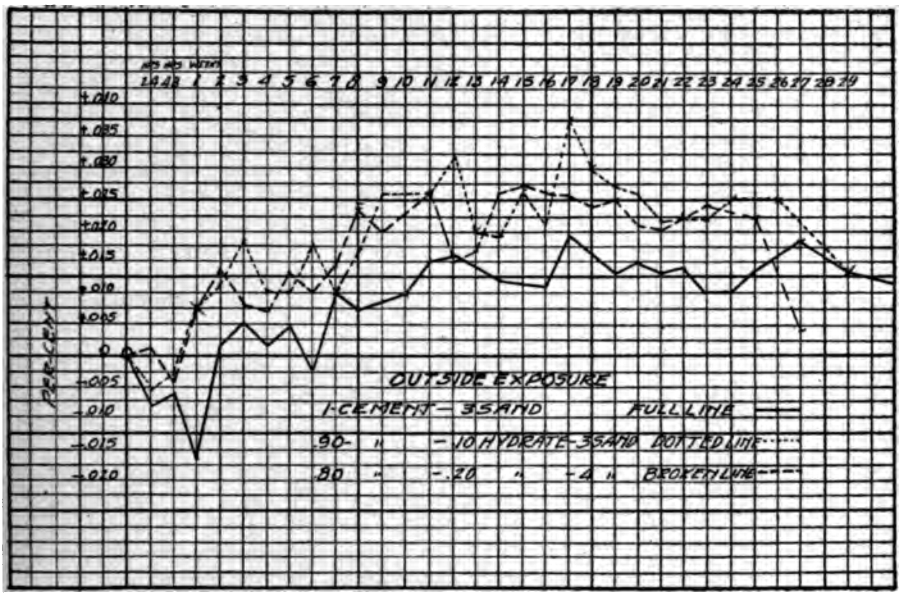


Fig. 6

The Effect on Expansion and Contraction in Test Pieces due to Variation in Moisture Content.

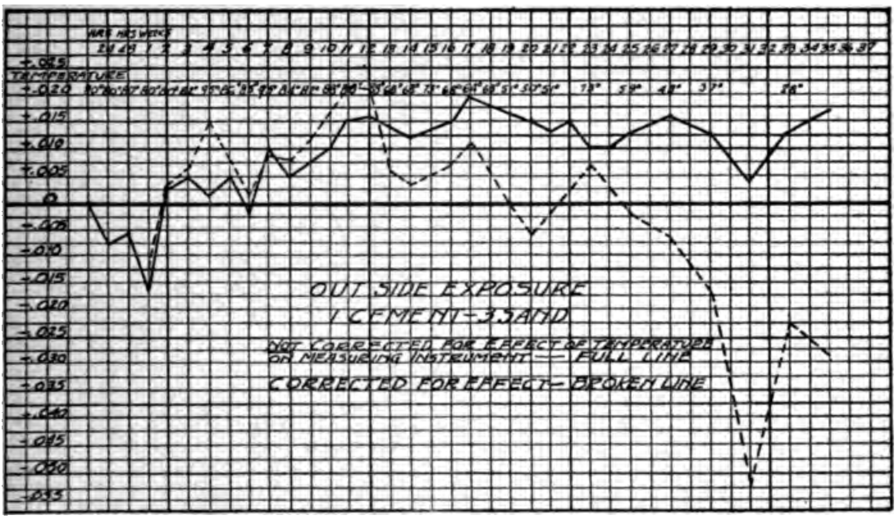


Fig. 7

The Effect on Expansion and Contraction in Test Pieces exposed out-of-doors due to the combined effects of *Variation in* Moisture Content and Temperature.

system of capillaries is established through which evaporation begins to take place and water is removed from the surface to be replaced by water, which finds its way from the interior. The rapidity of this movement depends upon the structure, whether the capillaries are fine and intricate or coarse and short. Open structure results in the maximum capillary flow, while close structure reduces the speed of drying. Since sponge-like colloidal matter with its immense surface and fine pores offers the greatest resistance to passage of water, it is obvious that the addition of finely divided colloidal material, such as hydrated lime, will greatly retard the flow of water whether due to gravity or evaporation, and gives opportunity for the mortar to obtain sufficient strength to resist the strains set up by shrinkage. This is indicated by the curves of the test pieces of Figures 4, 5 and 6 to which hydrated lime was added.

Mr. Gillette:—I want to call your attention to the progressive expansion of materials due to temperature. We have listened to a discussion of progressive expansion due to moisture. It is a well-known fact that the same phenomenon occurs with many materials, due to changes in temperature. A number of years ago experiments were made in cast iron, a substance which you would think would not change permanently because of changes and variations in temperature. Yet the cast iron continually grew. Each addition of temperature seemed to add a little to its length, and it never shrank back to its actual diameter, becoming progressively longer and progressively greater in diameter. This same phenomenon, I am satisfied, appears in concrete and I suggest it as a field for experiment.

Mr. Wig:—Laboratory tests should be very cautiously considered, as there are many factors in practice that are not covered in laboratory tests.

Mr. Spackman's experiments bring out many points coinciding with the Bureau of Standards, except the one of contraction of concrete during the first few hours. One point I wish to make in regard to expansion in the early stages is that often the heat developed by the cement is sufficient to cause some slight expansion of the concrete. Bituminous covered slabs show a greater modification than slabs that are not covered with bitumen. In averaging up the expansion we find the minimum expansion at a point where we get the lowest temperature and the greatest contraction where we get the highest temperature.

REPORT OF COMMITTEE II

JOINTS FOR CONCRETE ROADS

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The expansion joint should fulfill the following conditions:

(1) It should be located at the proper spacing—experience points to a distance of 25 to 30 feet when the pavement is not reinforced.

(2) It should be designed of sufficient thickness and depth to withstand the traffic.

(3) Metal should be hard enough to withstand abrasion but should not be brittle.

(4) The expansion joint protector should be simply installed.

(5) It should provide a strong bond with the load slab.

(6) The filler between the protectors should be plastic to permit expansion and contraction, and keep out grit and water. Both plastic asphaltum and tar felt paper are used with satisfaction.

(7) The protector should be as inexpensive as consistent with good service.

The subject of expansion joints for concrete pavements resolves itself into three divisions, namely, Location, Types and Maintenance.

LOCATION

When concrete pavement abuts curbing, all authorities, so far as we know, agree that there should be a joint filled with an elastic material permitting expansion in this direction, but there has been considerable diversity of opinion regarding the necessity of joints across the pavement, and if joints are used, just how far apart they should be.

There is unity of opinion that exceedingly long slabs without reinforcement will crack due to tensile stresses caused by fall in temperature or changed moisture, while there is again diversity of opinion as to whether the pavement without joints will buckle upon expansion due to increasing temperature.

REFERENCES

To obtain actual data on the foregoing, the U. S. Office of Public Roads, during the fall of 1912, under the direction of Hon. Logan Waller Page, built an experimental highway of concrete without expansion joints, using different aggregates and mixtures. Various reports on these experiments are found in the Engineering Record, June 28, 1913, and July 19, 1913.

The construction of this road, which was built at Chevy Chase, Md., was in charge of Mr. James T. Voshell, Highway Engineer, and the succeeding experiments *on contraction* and expansion were conducted by Mr.

A. T. Goldbeck, Testing Engineer, both of the Office of Public Roads at Washington, D. C. More specific information can probably be obtained from these men by direct correspondence than from the various magazine articles on the experiment.

As early as May, 1913, results of some expansion were noticed as stated as follows in the Engineering Record June 28, 1913, page 720:

"Until early in May there had been a range of temperature of about 90 degrees, and as the advancing warmer weather increased the expansion a vertical and horizontal displacement of about ½ inch was noticed at the juncture of the cement-concrete road with the section of bituminous concrete. This is the only evidence of failure due to lack of expansion joints in the mile of roadway."

Mr. A. N. Johnson, in the Fourth Report of the Illinois Highway Commissioners, 1910-12, page 83, after stating his reason for believing that joints may be spaced even farther than 50 feet apart with safety, continues, saying:

"The advantage of making the cracks beforehand is that their edges may be properly protected from traffic. It will be realized at the outset that the expansion joints constitute the weak points in the pavement, and that there should be as few of them as possible."

If a concrete pavement is laid without expansion joints, it might pass the first season without any serious consequences from buckling, as the cracks that are formed by the low temperature might not become sufficiently filled with incompressible material, but cracks afford some relief as the pavement expands under subsequent temperature rise. But as time goes on the cracks will become more and more filled with grit, become more nearly incompressible, so that in no very long time they will cease to be expansive and to afford any opportunity for movement of the pavement, which movement must then be taken up by deforming the concrete; and the stresses that will be induced by such deformation are beyond what is to be expected a thin slab can stand without buckling.

Mr. A. N. Johnson is quoted as follows, page 82, Fourth Annual Report:

"If the formation of cracks in a haphazard way is to be prevented, it will be necessary to provide joints close enough together that there will be sufficient strength in the concrete to drag ½ its length between joints.

"If expansion joints are placed from 40 to 50 feet apart, and on the assumption that the coefficient of friction of the pavement with the sub-soil is one, the tensile strength to be exerted as the pavement shortens under low temperature will be 20 to 25 pounds per square inch. While this is not too high an allowance for the tensile strength of concrete of the type recommended for concrete roads, it is evident that whether such a stress or greater one is exerted, depends entirely upon what is the coefficient of friction. However, there is every evidence to suppose that joints may be placed even farther apart than 50 feet with entire safety."

Hon. Frank Rogers, State Highway Commission, Michigan, page 708, Canadian Engineer, Nov. 15th, 1913:

"The writer does not believe that it is necessary to place expansion joints as close together as 25 feet. On three pieces of work constructed under his supervision in 1912, totaling 2.3 miles, none of the sections was less than 50 feet in length, many being 60 and 75 feet, and one or two as long as 100 feet. The number of cracks per mile in these roads at present is: Transverse cracks, 9.1; longitudinal cracks, 9.1 or 18.2 cracks per mile. The total *number of cracks* in the 1912 work on the Wayne County Roads, using

25-foot sections, is 19.1. It will be necessary to have much more data before it can be definitely concluded as to how frequent the joints should be; but from the observations that have been made it seems that the joints may be made further apart than 50 feet rather than nearer together."

Mr. George W. Cooley, in his report to the State Highway Commission, Minnesota, June 28, 1912, pages 6 and 7, says:

"Upon our return from Detroit, examinations were made of concrete pavements in the city of Chicago. There is considerable of 2-coat work in the residence districts, which were laid under the Blome Specification, and which have proven satisfactory, although they are cracked in a number of places. Some of these roadways were built with expansion joints 60 and 70 feet apart, and in such instances the cracks were more numerous.

"During our tour of inspection, I consulted with engineers and superintendents on this class of work and the consensus of opinion seems to be that for ordinary rural traffic a 6-inch thickness of first-class concrete, either with or without protection for expansion joints, and in sections about 35 feet long, is the proper style to construct on a width of 8 or 9 feet."

In the Seventh Annual Report of the Wayne County Commission is recorded a table giving the number of cracks in Wayne County Pavements. This data will probably be of interest as relating to the proper spacing of joints.

Several thousand yards of concrete pavements were laid in Mitchell, South Dakota, during the fall of 1912. These pavements were built in sections 12 feet 6 inches long and continuous across the width of pavement, which was 42 and 56 feet. Every second joint has a width of 3/8 inch filled with asphalt; the intervening joints have no width and afford protection only from contraction.

The Board of County Road Commissioners of Wayne County, Mich., in the beginning adopted a spacing of 25 feet for expansion joints and have maintained the practice on all their 82 miles of road with the exception of 450 feet on the Michigan Avenue Road which was opened to traffic Sept. 1, 1913. This stretch was laid in two sections, 150 and 300 feet in length, as an experiment to determine effects of the various forces to which the pavement is subjected. Reference to this experiment is found on page 13 of the Seventh Annual Report.

On Sept. 24, 3½ weeks after the opening of this road, an inspection of these sections was made by a representative of the Universal Portland Cement Co., who reported that cracks had developed at the following intervals:

One-hundred-and-fifty-foot section—12, 22, 18, 28, 27, 22 and 21 feet.

Three-hundred-foot section—22, 23, 45, 67 and 78 feet.

This inspection was made at a later date than that recorded in the Seventh Annual Report, and therefore should be taken as a supplementary statement.

These cracks were due to stresses developed in the concrete while hardening, and represent a condition which should be a factor worth consideration when selecting the proper spacing of joints, and yet it seems to be omitted entirely from the foregoing quoted discussion.

On July 19th, 1913, a representative of the Universal Portland Cement Co. made an inspection of the concrete pavement on Warsaw Street, Toledo, Ohio. This report states that expansion joints were omitted from the pavement North of Dexter Street and that in consequence several cracks have developed. At some of these cracks it is stated that the concrete is crushed to a distance of *4 inches* from the crack and there was on this date

vertical displacement of from ½ to 1 inch of the slab on one side of each of the cracks. The most conspicuous of these failures is reported as follows: "North of Park Street there are no joints permitting of expansion for a stretch of 250 feet. At that point there is a crack which is broken out to a width of 4 inches in places, the concrete being apparently crushed. The slab on one side of the crack has overridden the other, thus causing a vertical displacement of 1 inch."

These investigations and the foregoing data would seem to indicate: That concrete contracts upon hardening, causing stresses which result in cracks forming at various intervals but indicating that nature is favorable to a spacing of from 20 to 30 feet. That transverse stresses may be developed from contraction or expansion over uneven surfaces, also from heaving or settling of foundation. That concrete in long slabs may exert forces resulting in crushing of the concrete and vertical displacement of surface.

The Seventh Annual Report of the Board of County Road Commissioners of Wayne County to the Board of Supervisors of Wayne County, dated September 30, 1913, reports the following:

"The only serious objection that has to date been advanced against the construction of concrete roads is the development of cracks. We do not consider this a material objection, and believe that the formation of cracks can be minimized by careful workmanship, a well prepared subgrade and proper drainage. We believe the difficulty can be practically eliminated by reinforcing with mesh wire or other suitable material. This entails an additional cost of from 10 cents to 12 cents per square yard. We have not gone to this extra expense, as we feel that by filling whatever cracks develop with Tarvia X applied hot and covered with coarse sand, we prevent wear and obtain a smooth, even surface. To date this has been done at a less cost annually than the interest on the reinforcing cost at 4 per cent would amount to.

"The first roads built by us have developed by far the largest number of cracks, and caused us to change our specifications to those now in use. We have carefully counted the cracks on over 45 miles of concrete roads built previous to January 1st, 1913. Every break was counted as either a transverse or longitudinal crack, irrespective of whether it extended the entire width or length of the slab or only extended a foot. Diagonal cracks were counted for the most part in the longitudinal column. Such cracking as develops usually shows within the first year, and we propose making a yearly count to determine to what extent if at all the cracking continues after that time. All roads are put down in 25-foot sections with a transverse metal protection joint. No longitudinal joints are used.

Road	Year Built	Cracks Trans.	Cracks Long.	25-foot Sections	Date of Count	Course
Woodward	1909	34	80	211	Aug. 23	2
Woodward	1910	22	34	254	" 23	2
Gratiot	1911	13	12	326	" 23	1
Mt. Elliott	1910	22	3	172	" 23	2
Mt. Elliott	1911–12	15	1	186	" 23	1
Grand River	1909	2	14	64	" 23	2
*Grand River	1910	49	59	342	" 23	2
Grand River	1911–12	66	96	1,748	" 24	1
Fort	1912	28	2	453	" 24	1
Van Dyke	1910	11	14	211	" 24	2
Van Dyke	1911–12	9	15	254	" 24	1
Jefferson	1912	6	31	346	" 24	1
†Michigan	1910	52	240	479	Sept. 1	1
Michigan	1911–12	122	287	3,071	" 1	1
River	1910	5	55	149	" 1	1
‡River	1911–12	34	213	855	" 1	1

*Built by Owosso Construction Company.

†This section of Michigan Avenue Road is built partially on the old road-bed, and partially on a fill which is responsible for the large number of cracks developed.

‡Taken from count made by State Highway Department.

EXPERIMENT IN THE ELIMINATION OF JOINTS

"On the far end of Michigan Avenue Road 2 sections of concrete 16 feet wide were constructed without expansion joints, one 400 feet long and the other 150 feet long. Both sections were opened for traffic September 1st, having been kept closed for over 3 weeks after construction. Transverse cracks have already developed; the 400-foot section shows 5, and the 150-foot section, 6 cracks. From this and previous experiences we believe it to be the better practice to make the cracks when building the road so that the edges be properly protected from traffic. For this purpose we use steel joints manufactured for work of this nature, and cut to fit the crown of the road."

From Specifications for Concrete Pavements of Board of County Road Commissioners of Wayne County, Michigan:

EXPANSION JOINTS

"To allow for expansion the pavement shall be built in sections 25 feet in length, and at each end of each section a soft steel plate 3/16 of an inch thick, extending the entire width and depth of the road, shall be imbedded in the concrete and fastened to the section by projections from the steel or in some other manner satisfactory to the Board. It is hereby expressly stipulated that the joints furnished by the R. D. Baker Company, Home Bank Bldg., Detroit, will be satisfactory. Between these sections, cutting the entire depth of the concrete, shall be placed an asphalted felt, about ⅛ of an inch thick.

"Special care must be exercised to have the expansion plates flush with the surface of the road so that there will be neither an elevation nor a depression at the joint."

TYPES

When building the older concrete pavements, the tendency was towards wide, unprotected expansion joints at intervals, with the intervening slabs cut into smaller slabs of from 6 to 9 feet square. The small squares were the first to be eliminated and then the width of the joints began to decrease.

This type of joint was used universally until about 3 years ago and is to some extent used now on pavements having light traffic. The method of construction is as follows: A plank, preferably bevelled sheet siding, bevelled cast iron or smooth steel plates, is oiled and set up as a bulkhead at the joint line. After the concrete has been deposited, finished and edged along each side of the bulkhead it is withdrawn; afterwards the space is filled with an asphaltic compound which does not flow under summer temperatures or become brittle and chip out in cold weather.

Originally this joint had a width of 1 inch or greater, now it is conceded that ¼ to ⅜ inch is sufficient on slabs having a length of from 25 to 50 feet. This joint has not given any great success. Whether this is due to the fact that they are not kept filled is a question; but since it is a fact that they are not giving complete satisfaction and that they are somewhat objectionable in appearance, those interested in the improvement of the concrete pavement have developed other types of joints.

The first development to eliminate wearing of joints was naturally in the form of steel protection, and on Woodward Ave. Road, Wayne Co., during the summer of 1909 a section of pavement was laid having 2 angle irons laid back to back, ⅜ of an inch apart, and bonded to the concrete with projecting bolts. The upper leg of the angle lying on the surface was found to be objectionable because it did not wear at the same rate as the concrete. The second advance was made by Mr. R. D. Baker of Detroit, who designed and made some plates used on the Wayne roads during the year 1910. These plates were of 3/16-inch by 3-inch soft steel with bonding arms ½ inch by 6 inches, sheared from the center of the plate at 1-foot intervals and bent outward at right angles. The plates were bent to the crown of the road and clamped between them were three strips of ⅛-inch by 6-inch tarred felt. The section after assembling was staked in position across the road. It was found, however, that the section was not of sufficient stiffness to hold it in true line with the pressure of concrete on one side only. This led Mr. Baker to design an installing device; and later the steel section was made of two ⅛-inch by 2-inch plates. This joint was so satisfactory that it has been used on all of the Wayne County road work in the last three years. Complete information may be had on this plate and device by writing the R. D. Baker Co., Detroit, Mich. A report on the experiments with the steel protection plates and the subsequent adoption is found on page 4, Fifth Annual Report, and page 58, Sixth Annual Report of the Board of County Road Commissioners of Wayne County, Michigan.

The Trussed Concrete Steel Co., of Detroit, Mich., have patented a plate. It is called an armor plate. The depth of plate is 2½ inches; the thickness of the body full heavy ⅛ inch; anchors are punched out from the plate and are 6 inches long, spaced 12 inches.

The Puffer-Hubbard Manufacturing Co., Minneapolis, Minn., during 1913 applied for patent and started manufacturing a plate and installing device similar to the Baker plate, excepting that the plate anchor is a loop pressed out or expanded from the plate.

When the Baker plates were first used, they were clamped to several thicknesses of tarred felt paper. Arranging and keeping these sheets together was troublesome and on this account some builders clung to the sheet of steel bulkhead, clamping the plates to the steel and afterwards removing the steel bulkhead, leaving the space to be filled with hot asphalt. This led to the manufacture of a product known as "Carey Elastite," a mixture of asphalt and wool fibre which is obtained in thickness of from ⅛ to 1½ inches and in any width. This material is manufactured by the Philip Carey Co., Lockland, Cincinnati, Ohio. This material also simplifies the construction of joints between curbing and pavement. Instead of the old method of placing a form which is withdrawn the "Elastite" is placed against the curb and left there. Those joints and any others not subject to traffic wear are not protected with steel plates.

Heretofore, practically all specifications for concrete pavement have advised joints ½ inch or wider between pavement and curb while for transverse joints ¼ inch or ⅜ inch is deemed sufficient. Based on the theory of expansion, the joint at the curb is entirely too wide and ¼ inch at each curb would be ample for pavements in widths up to 50 feet. When Elastite or other similar compressible compounds are used there is no reason why the joint should be wider than necessary but where the joint is made with a bulkhead, afterwards drawn, the half-inch joint gives better results in construction and in filling with hot asphalt afterwards.

Descriptions of two types of steel angle joint protectors will be found in Concrete-Cement Age, August, 1913, Vol. 3, No. 2, page 77, and Engineering & Contracting, Nov. 22, 1911, page 545. An altogether different type of joint designed by H. F. Hall of the Wright-Hall Engineering Co. is described on page 459 of Engineering & Contracting for Nov. 1, 1911.

A concrete pavement was built at Mattoon during 1912, in which a row of paving brick was used at expansion joints and during the same year the Illinois Highway Commission built a concrete road at DeKalb; on part of this road creosote paving blocks were used at expansion joints. Both of these experiments proved unsatisfactory.

MAINTENANCE OF JOINTS

Expansion joints should be kept filled to the level of the pavement surface so that there will not result an impact when wheels cross the joint. If the joint is not kept filled, grit will accumulate and in time the joint will be filled with non-elastic material. Even a joint which has been kept filled will in time become jammed with grit.

REFERENCES

Engineering Record, June 28, 1913, page 719, Description of Chevy Chase Experimental Road.

Engineering Record, July 19, 1913, page 76, Description of Strain Gage used by A. T. Goldbeck in Experimental Tests in Chevy Chase Experimental Road.

Proceedings American Society of Civil Engineers, September, 1913, page 1683, page 1693. Attention page 1686, Mr. Thompson's discussion; page 1691, next to last paragraph of Mr. Whinery's discussion.

Canadian Engineer, November 13, 1913. Article on Concrete Roads by Hon. Frank F. Rogers, State Highway Commissioner of Michigan.

Municipal Journal, Sept. 25, 1913, page 419, Concrete Roads in Milwaukee County.

Fourth Report, Illinois Highway Commissioners, 1910-11-12, page 82, Expansion Joints.

1913 Good Roads Year Book, page 166.

"Joints.—To provide for free movement of concrete the road should be laid with joints of 1/8 inch width not more than 25 feet apart. Such joints should be vertical and extend entirely through the center. They should be filled with tar paper or a waterproof filler."

Engineering & Contracting, Oct. 22, 1913, page 450, Report of Survey of Wayne Co. Pavements.

DISCUSSION

Mr. Kerr:—On the subject of Joints for Concrete Roads, I feel that there is but little that I can add at the present time, and that further experiments and actual service tests will undoubtedly furnish us with valuable data on this subject.

As has been shown by the report of Committee I on contraction and expansion of concrete roads, there is a contraction which takes place due to the drying out of the concrete and also due to temperature change which results in cracks, and since these cracks occur, it seems better practice to provide joints in the concrete to take care of them than to allow them to be formed haphazardly by nature. By providing for this contraction we can secure true alignment and have the joints properly protected, if a protected joint, or if an unprotected joint, we can have the concrete at the joint rounded off to a slight radius so that it will better allow the filler and make the maintenance much easier. It seems pretty definitely decided that joints should be placed longitudinally along the sides of a road when the sides are bound, as in the case of a city street, by curbs, but the spacing of the transverse joints is a question which I hardly believe can be decided upon uniformly for all conditions. In other words, I do not believe that we can state that the transverse joints should be placed at a certain distance apart, as their spacing will depend upon the conditions of the sub-grade, climatic conditions, and the quality of the concrete, as has been pointed out in the report of Committee I. I feel that in each case these conditions should be studied before building a road, and after they have been duly investigated, the spacing of the joints should be as carefully worked out as possible.

The finishing of the concrete at the joint should be carefully watched so as to have it uniform. The concrete should be properly brought up to the expansion joint and troweled towards the joint, bringing there enough mortar to thoroughly surround and unite the particles of gravel or broken stone. At this point the concrete will receive some of the hardest wear and it is particularly important that it be of good quality.

As to the kind of joint, both the protected and unprotected are used, and I am not prepared to say which will ultimately give the best results. I believe that either joint is a good joint when properly built. If the steel will wear at practically the same rate as the concrete in the protected joint and provide a smooth surface at this point, it certainly affords a good protection to the concrete. In the case of the unprotected joint it is a good plan to round the concrete at this point to a radius of say 1/2 inch and then cut off the tar paper or asphaltic felt a half inch or so above the surface of the concrete and allow this to be tamped into the joint and worn off by traffic.

The maintenance of the joints is an important consideration. They should be carefully watched and when the elastic material has squeezed out in hot weather, or has become worn away, the joints should be cleaned out and refilled. Rigid material should be excluded from the joint, as its filling with such a substance would prevent the expansion of the concrete and cause undue compressive stress. Considering only the movement which the concrete is considered as having, namely .00054 per unit of length for a change in temperature of 90 degrees, and assuming a modulus of elasticity of 2,000,000 pounds per square inch, there would result in cases of expansion with the ends fixed, a compressive force of about 1,000 pounds per square inch. This would result in buckling in the thin slab of concrete. I have, however, never observed a concrete road that buckled, but there have been cases of concrete sidewalks doing this, and I feel that precaution should be taken to keep the joint in proper condition and avoid this possibility. Another reason for keeping the joint properly filled with tar or asphaltic compound, is to prevent the penetration of water through the joint to the sub-grade, as water in the sub-grade, especially in freezing weather, would no doubt cause considerable trouble.

Mr. Tunnicliff:—I would like to bring before the Convention an idea that I have; that is, that the so-called expansion joints are not put to the functional use that their name would imply; that is, that the expansion that they provide for is very seldom evidenced, and I think that whatever joints are used in the construction of the concrete pavement should be made to take care of contraction. I think the name expansion joint will be discontinued.

Mr. McIntyre:—I wish to call your attention to one point which Professor Hatt did not bring out—the necessity for the joint being perpendicular to the surface of the slab. If the joint is at an angle there will be an opportunity, when the concrete expands, for one slab to slide upwards and cause a bump in the road. I have in mind a particular instance of a concrete road built on a 5 per cent grade. In this case the indications point to the fact that due to expansion one slab had a tendency to move down hill. The adjoining slab down the hill was apparently held in position by the friction on the sub-base. The upper slab slid upwards at the joint. Upon examination it was found that the joint was at an angle with the surface. Had this joint been perpendicular there would not have been an opportunity for sliding since full bearing at the joint would have been developed.

Mr. Larned:—I would like to ask if in the experience of anyone, in the construction of concrete roads, they have reached the conclusion that metal-bound joints could possibly be omitted. We seem to be providing for contraction, and yet that contraction is more or less overcome by expansion due to moisture content. Now the entire movement of the joint will perhaps be very small, and a very considerable item of expense could be avoided if we could omit the metal-bound joint.

Mr. Hubbell:—In Davenport, for the years of 1912 and 1913, the specifications called for creosote block expansion joints, and we have found after 2 years' service that these joints have met the requirements expected. We have found that they are not really expansion joints but contraction joints. The creosote block half an inch or an inch thick, running the full depth of the pavement, protects the edges of the concrete. The block has a tendency to broom open and protect the edges on either side, and we have

found that the edges do not break and that it is not necessary to put in any steel plates. The block is a cheap form of filler and has answered all the purposes in Davenport.

Mr. Gillette:—In answer to the query about the omission of expansion joints, I would say that the specifications for the State of California are drawn so that expansion joints are not provided except in special cases. Sixty or seventy miles of concrete road are now being built without any expansion joints whatever. Los Angeles County has built some 300 miles of bituminous macadam and concrete, omitting expansion joints. One strip of concrete, which I visited a short time ago, is laid without any expansion joints. The strip is 4 miles long, 16 feet wide and 5 inches thick, and there is not a crack either longitudinal or transverse in the whole strip. One reason for this absence of cracks may be, perhaps, that the foundation was compacted by a roller tamper. This tamper gave a foundation so solid that you could not drive an oak peg into it. I think one of the secrets of freedom from contraction in concrete roads lies in a solid sub-base.

Mr. Boley:—The city of Sheboygan has a considerable yardage of concrete on its streets. We have not used armor on the joints. In reply to the question which was asked, we have had no trouble with the spalling off of the joints and at the present time see no very good reason for putting on a metal protection. I do not know what the experience would be on the country road, with a roadway 16 to 18 feet wide, but we certainly have had no trouble during our 3 years of experience. We used an asphalt filler for the early streets. In our later work we have used a felt joint. Both gave satisfaction.

The remarks in regard to the greatest expansion and greatest contraction of concrete do not agree with my observations. I have not found the time of greatest expansion to be in cold weather. Within the past few days, which have been cold, I have noticed on our concrete streets that a knife blade could be inserted at the joints between the filler and the concrete slabs. It would seem that cold weather was causing contraction rather than expansion. During the hot weather the filler which is placed in the joint is forced upward sometimes half an inch. On extremely hot days the filler bulges up and pours over on each side of the joint. It never goes back, but is spread out and rolled out by traffic. This condition seems contradictory to the experience that has been given.

Mr. Wig:—I think we can explain the point in regard to the expansion of the filler as due partly to the expansion of the filler itself, and due also partly to temperature. It was not the idea to make the statement that we have no expansion with increased temperature, because we have; and we also have contraction with moisture and a sudden change in contraction with a drop in temperature. With a sudden change in temperature we have a sudden change in the concrete; and if the temperature drops the concrete tends to contract. The intention of the statement was that during the winter months we get a gradual expansion of the concrete and during the summer months a gradual contraction.

Mr. F. P. Wilson:—In the past 8 years I have designed and constructed between 50 and 60 miles of concrete streets, and I have found from actual experience that the only successful method of protecting the concrete is to use steel plates on each side of the joints. I have experimented with paving bricks at the joints; I have experimented with so-called creosote

wood strips. I have found that the only practical, durable, reliable protector to use is the steel plate on each side of the joint. These plates are about 2½ inches in depth and ¼ inch in thickness with shear members imbedded at right angles into the concrete. When I used the brick joint with an elastic filler, the corners broke down. When I used just the filler without any protection the results were the same.

In regard to the theory of concrete expanding in winter and contracting in summer, my observation does not support the theory.

Mr. Mullen:—In Minnesota our experience has not been very extensive, but we have built considerable concrete road without using metal protection plates at the joints. The first roads that we built were planned with expansion joints, 25 feet apart. These joints were ⅜ of an inch in width and filled with asphalt filler. After we had done considerable building we learned that it would be better to place expansion joints 60 feet apart with contraction joints at 20 feet. This practically eliminated cracks except where the materials used were poor. The wear at the joints was not noticeable when the material and workmanship were good. On some of the roads that were built last year it happened that we got a poorer grade of sand and at places where that sand was used the expansion joint broke down. The roads built were 8 feet in width, which confined the traffic in a very small area. The wear at the joints was very heavy but where the material was good, where the sand especially was good, I should say there was no notice of wear at the joints. Wherever there was foreign matter in the sand, the joint showed considerable wear.

Mr. Thompson:—It seems to me that where there is such a difference of opinion as we have heard expressed, about whether or not metal plates were necessary, that the need of metal joints may depend to a certain degree at least upon the character of the concrete. If we have very strong, hard concrete, made of the very best materials, it is very possible that our corners may be sufficiently strong to withstand the abrasion and hammering of traffic. In Sheboygan, if I am not mistaken, they have very excellent sand for use in their pavement. In other places where the sand is less good and the concrete more soft, metal-bound joints may be absolutely necessary. With good materials, simply leaving a space between the slabs might be enough. There is a question too, whether the quality of concrete does not cause the expansion and contraction about which we have had a difference of opinion. If concrete is porous the moisture penetrates it, which tends to expansion. Where the concrete is very dense and very dry it is subject to the influence of heat and cold, the heat tending to expand and the cold tending to contract the concrete.

Mr. Tunnicliff:—I do not think that Mr. Thompson meant to convey the idea that poor concrete would be substantially helped by the use of a metal joint. It seems to me that in a concrete road that was not capable of standing considerable abrasion a metal joint would really be a detriment; that is, the joint would withstand the traffic and the concrete, being soft on either side of the joint, would be inclined to wear away. I think it is of importance in the use of metal joints to take into consideration the hardness of the aggregates.

Mr. Whitmore:—The discussions before the conference have indicated a great variance of opinion as to the cause of the cracks in concrete pavements, which the so-called expansion joints are intended to remedy.

I wish to state that my observations along this line have thoroughly convinced me that longitudinal cracks are seldom or never caused by contraction or expansion, and that they are practically all caused by heaving of the sub-grade by freezing, and occasionally by unequal settlement of improperly prepared sub-grades. This opinion is based on the following observations:

(a). These cracks usually appear, if not always, in the form of a very small and insignificant appearing crack when the snow goes off in the spring.

(b). Where the sub-soil is clay, the cracks are found where ample expansion joints are provided at the curbs, as well as where there are no expansion joints.

(c). Where the sub-soil is sand or gravel with good natural drainage, or on fills or steep grades where the drainage is good, these cracks are absent, even where there are no expansion joints at the curb.

(d). The cracks follow along the line of travel on the street, usually along near the crown, where the snow is packed by traffic during the winter. Nearly everyone has observed that the frost will penetrate to a depth of several feet in a roadway when there is no frost whatever under the snow along the sides. Where there is a car track along the center of the street and the soil is of impermeable clay or of such a nature as to hold water, there is usually a crack along the driveway each side of the tracks about midway between the rail and the curb. At intersecting streets which *cross* the paved street, the crack does not continue across the intersection, presumably because the travel across the street and around the corners packs the snow and permits the frost to penetrate over sufficient area to raise the pavement uniformly without breaking it, but where the intersecting street comes in *from one side only,* the crack runs off toward the opposite curb as it approaches the intersection, and continues past the intersection, coming back to the crown again on the other side.

(e). A careful examination of the concrete foundation under the longitudinal crack in the surface of a brick pavement will reveal the fact that the foundation is also cracked. Expansion does not seem to account satisfactorily for this.

Most of the observations briefly outlined above have been made during the past 10 years in studying brick pavements; but it seems logical to assume that the same causes that produce cracks in brick pavements will produce them in concrete.

Good artificial drainage at the curbs will assist in preventing the subsoil from becoming sufficiently saturated as to be heaved by freezing; but under some conditions this result cannot be entirely accomplished. I therefore believe that it is necessary to build a stronger pavement where the soil is liable to heave when frozen.

Professor Hatt:—My own view of this subject, apart from the committee, is that in line with other forms of concrete construction we ought to look to the elimination of the joint and reinforce the road with steel.

REPORT OF COMMITTEE III

AGGREGATES FOR CONCRETE ROADS

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The successful development of the concrete pavement depends upon: (1) Materials, and (2) Workmanship.

It is not so much a question as to whether concrete is a suitable material for roads in comparison with other paving materials, as it is a comparison between concrete and concrete. The durability depends upon the character of the concrete.

Suppose we were to build a brick pavement. Assume that we start with a poor foundation; we lay the brick at unequal distances apart; we half fill the joints; and for the brick we use a soft, light brick. Will the pavement stand? Suppose all the workmanship is satisfactory and the brick alone is poor, shall we expect the pavement to be durable? Certainly we cannot condemn brick pavements in general because such a pavement as this does not last.

But is not this exactly what many people may expect of a concrete pavement? They lay on a poor foundation, improperly mix and place the concrete, and use materials that will not make concrete good for any purpose. They may, in fact, properly prepare the foundation, mix the materials thoroughly and in correct proportions, but provide sand that is fine and stone that is soft, and then they condemn not this pavement in particular but concrete pavements in general.

It must be remembered, however, that the general public has a perfect right to condemn concrete pavements in general if a large number of concrete pavements are poorly built or are built of poor materials.

It is to prevent just such improper work that this convention has been called, and the publicity which will be given to good methods of construction should lead to widespread improvement in methods of construction.

Examination of letters received by the Chairman of this Committee from a large number of cities having concrete roads shows general satisfaction with this type of pavement. Adverse criticism usually comes from cities where the specifications and description of work indicate either poor materials and incorrect proportions or improper methods of construction.

AGGREGATE ESSENTIALS

Tentative specifications for aggregates are given at the end of the report. Simple rules covering the most essential requirements are as follows:

(1) For fine aggregate, use only sand or other fine aggregate that has been actually tested for mechanical analysis and tensile strength of mortar, and is free from *fine particles*.

(2) Use coarse grained sands or hard stone screenings with dust removed.

(3) Use sand or other fine aggregate that is absolutely clean.

(4) For coarse aggregate, use hard stone, such as granite, trap, gravel, or hard limestone.

(5) If bank gravel or crushed stone is used, always separate the sand or screenings and re-mix in the proper proportions.

If local conditions prevent following any one of these rules, adopt some other material than concrete for your pavement.

Briefly taking up each one of these points:

(1) Actual laboratory tests are necessary for fine aggregates, because it is impossible for the most expert builder to always distinguish by appearance between good and poor sands. Sand may be coarse, of good color, well graded, and apparently perfectly clean, and yet because of a minute quantity of vegetable matter may show practically no strength when made into mortar or concrete. Case after case has been found where good looking sand had to be rejected on laboratory test or, if used, produced defective concrete.

Note that two tests are given in the specifications—for fineness and for tensile strength of mortar.

(2) Coarse sand is necessary not only for strength and density, but to prevent the formation, on or near the surface, of a layer of fine material, consisting of a mixture of dust and cement which has no durability. Mortar made with fine sand or sand having a large proportion of fine grains of silt, hardens slowly and is especially objectionable in cold weather. This prevents it attaining proper strength before the road is thrown open to traffic. A sand having a considerable proportion of fine particles may possibly show high briquette tests, and yet the mortar not have good resistance to attrition or wear.

As indicating the necessity for coarse sand, even when the mortar made from it is high in strength, various cases might be cited; one, for example, in Wisconsin, where the sand mixed into mortar showed high tensile strength, and yet, because of 10 per cent of silt in the sand, the surface of the road was entirely unsatisfactory, and had to be covered with a bituminous wearing surface after less than a year's service. A natural sand of limestone composition frequently shows high strength in mortar, but may be poorly adapted to pavements because of an excess of fine grains.

(3) Sand must be absolutely free from vegetable or organic matter, or it is liable to harden not at all or too slowly to be serviceable. Frequently, sand may be entirely satisfactory in appearance, and yet be worthless for concrete. Defective sand of this type is apt to be taken from too near the surface of the ground, so that it contains a very small percentage of vegetable loam. At least 2 feet of top soil and loam should be removed before using the sand, and in many cases it is necessary to take off as much as 4 or 5 feet, while occasionally no acceptable sand can be found in the entire bank because of the penetration to a great depth of the deleterious vegetable material.

In one case, in Wisconsin, the materials were distributed along the entire length of the road that was being improved. The laying of the concrete was discontinued before the road was completed, and for several months traffic drove over the sand and gravel that was later used in the construction

of the concrete pavement. The portion first built was good, while the other part was very defective. The cause of the difference, evidently, was due to the dirt and manure that had become mixed with the aggregates.

(4) A coarse aggregate of hard quality is necessary to resist the wear and abrasion of hoofs and wheels. Failures of concrete roads have been caused simply by the softness of the coarse aggregate. In one instance, for example, shells were used for the aggregate, and the road went to pieces as soon as it was subjected to wear.

All stone, like shale, slate, shells, and soft limestone, must be rejected; while trap, granite, and conglomerate, are especially suitable materials. A hard limestone, such as that occurring in certain localities along the Hudson River, which is sold in New York as trap rock, is satisfactory for concrete roads. A hard limestone cannot be cut with a knife and the specific gravity is high, say, over 2.70.

Gravel does not bond quite so strongly with cement as does broken stone. When properly screened and free from dirt, however, and remixed with sand in the proper proportions, a good surface can be made even for a 1-course pavement.

(5) Many roads that are now being built will prove worthless because of the use of sand taken directly from the bank without screening. If the gravel contains as much as 40 per cent of stones and very rich proportions are used, say 1 part cement to 3½ parts bank gravel, a fair concrete can sometimes be produced, but it is always cheaper in such cases to screen the gravel and remix the sand and stone in proper proportions. There will be, for example, a saving of ¼ barrel, or 1 bag, of cement per cubic yard of concrete by using proportions 1 part cement to 2 parts sand to 3 parts screened gravel, instead of using the unscreened bank gravel in proportions 1 to 3½. This difference will more than pay for the additional cost of screening the sand and rejecting part of it. At the same time, the result will be more uniform and the surface more durable because of the stones which take the wear. When an excess of sand is used in the mixture, as is the case with run-of-the-bank gravel, the mortar rises to the top when the concrete is placed and the wearing surface is less resistant than a mix that is uniform throughout.

If the rules given above are followed, and at the same time proper foundations, proportions, and workmanship, are obtained, the concrete pavement will prove durable and will resist ordinary traffic.

AGGREGATE SPECIFICATIONS

Tentative specifications for aggregates are presented as follows:

FINE AGGREGATES

Quality

Fine aggregate shall consist of sand or screenings from hard, durable gravel, granite, trap, or other hard rock. It shall be clean, coarse, hard, free from dust, loam, vegetable, or other deleterious matter. Fine aggregate containing frost or lumps of frozen materials shall not be used.

Samples for Test

Average samples of fine aggregate weighing not less than 10 pounds shall be taken from the bank or pile and tested, before the acceptance of the

material, for fineness and for tensile strength in mortar. Individual average samples shall be taken from each bank to be used, and new samples taken in case of a change in the character of any one bank.

Receptacles for shipment to laboratory shall be such as to retain the natural moisture in the sand.

Fineness

The size of the fine aggregate shall be such that the grains pass when dry a screen having ¼-inch openings. In the field a ⅜-inch mesh or, in some cases, a ½-inch mesh screen may be used for this separation.

Not more than 10 per cent of the grains below the ¼-inch size shall pass a sieve having 50 meshes to the linear inch, and not more than 2 per cent shall pass a screen having 100 meshes to the linear inch.

Tensile Strength of Mortar

Mortars composed of 1 part Portland cement and 3 parts fine aggregate, by weight, when made in briquettes shall show a tensile strength at least equal to the strength of 1:3 mortar of the same consistency, made at the same time, and with the same cement and standard Ottawa sand. The sand shall not be dried before being made into briquettes, since this sometimes improves its quality, but correction shall be made for moisture when weighing the materials.

Tensile tests may be made at ages of 72 hours, 7 days, and 28 days. At early periods the strength need not attain the full ratio of 100 per cent to standard sand mortar, provided this is attained at a later period. In no case, however, shall sand be accepted for pavement work whose strength in 1:3 mortar at the age of 72 hours is not at least 80 per cent of the strength of the standard sand mortar.

Screening

If the sand does not fulfill the above requirements for fineness, it shall be washed or else screened when dry over a 10 mesh screen placed at such an angle as to remove the particles finer than a No. 50 sieve.

Washing

Fine particles may be removed by washing with a large volume of water in a box provided in the bottom with perforated pipes and arranged for the silt and water to flow off through a trough from the top of the box and the sand to be drawn out from below.

COARSE AGGREGATE

Quality

The coarse aggregate shall consist of clean, hard, durable granite, trap, conglomerate, gravel, or other hard rock, free from dust, loam, vegetable or other deleterious matter. In no case shall coarse aggregate be used which contains frost or lumps of frozen material.

Coarse aggregate containing soft particles shall be rejected.

Coarse aggregate shall not contain a large proportion of flat or elongated particles.

Fineness

For 1-course pavements, the size of the coarse aggregate shall be such as to pass an inclined or rotary screen having 1½-inch circular openings and be retained on a similar screen having ⅜-inch openings.

For 2-course pavements, the size of the coarse aggregate for the bottom course shall be such as to pass an inclined or rotary screen having 2-inch openings and be retained on a similar screen having ⅜-inch openings.

For the wearing course in a 2-course pavement, the coarse aggregate shall be of a size that will pass an inclined or rotary screen having ¾-inch circular openings and be retained on a similar screen having ¼-inch openings.*

NATURAL MIXED AGGREGATES

Natural mixed or crushed aggregates shall not be used as they come from the bank or crusher, but shall be screened and remixed in the proper proportions.

DISCUSSION

Mr. Thompson:—There is one point in this report about which I wish to speak. The statement is made, in that part of the report dealing with aggregate essentials, that a natural sand of limestone composition frequently shows high strength in mortar, but may be poorly adapted to pavements because of an excess of fine grains.

That is a point that I have never heard brought out—the action of the limestone aggregate on cement. Frequently, one gets a high strength with limestone sand, and limestone sands are quite common in certain parts of the country. In Canada, some time ago, I got nine specimens, all but one of which were almost entirely limestone. In New York City, in many places, I have found sand with many limestone particles.

Another point of importance in the report is mentioned under the caption "fineness."

In many parts of the country it is impossible to get sand meeting the requirements without screening the sand over a fine screen. But if we are going to have durable concrete roads we must have not merely good workmanship but also good material, and that is the only way in which concrete roads will prove durable and make a permanent place for themselves as a concrete pavement.

Mr. Larned:—The importance of fine and coarse aggregates needs especial emphasis and particular emphasis on the fine aggregate. But in considering the specifications for the fine aggregate I think it is well to consider the average commercial condition. We cannot expect to go into too great refinements without great discouragement to the work.

Now the requirement that 100 per cent strength be developed by a natural bank sand is very good; in fact a first class natural bank sand will test better than Ottawa sand but there is a large range of perfectly good sands that produce a good concrete that will not produce 100 per cent of the strength developed by Ottawa sand. In the last 2 or 3 years we have heard tentative specifications suggested for sand and it has been pretty generally the custom to require that sand be 70 or 75 per cent rather than 100 per cent of the strength of Ottawa sand. And I think the use at the lower percentages is a little more practicable than if we get into greater refinements. The question of

* This assumes a perfect bond between the first and second courses.

the granulometric composition of sand, in which it is suggested that in all cases not more than 10 per cent shall pass a fifty mesh sieve, I take issue with. What we seek to exclude in sand is fine materials; and anything that passes a fifty mesh sieve goes a long ways toward passing a hundred mesh sieve. If you require primarily that a coarse sand be used you know that you will not get excess of material passing a fifty mesh sieve. If you have in the coarse sand material passing 5 or 10 per cent through a hundred mesh sieve, you have something worthy of suspicion; and that is the material we want to avoid. I know from having tested a great many sands, that we get better results with commercial sand that will carry from 25 to 30 per cent through a fifty mesh sieve, and that sand will be found to be a little more practicable than if we attempt to limit the content to only 10 per cent.

Professor Baker:—It seems to me that this report might well be considered in connection with the very valuable report of Mr. Wig. It has been emphasized in this report that we must have sands that will give us certain strength in concrete. Strength is all right, but it seems to me that after all the most important thing is to keep water out of the road. We do not make a rich mixture for a concrete road necessarily so much to get great strength as we do to make as nearly as possible an impervious concrete. Mr. Wig's paper shows very well the reason why. The more we have the condition of alternate wetting and drying, the more movement and stresses we are going to set up in the concrete. Now tests have shown that some percentage of fine material in the sand sometimes gives a more impervious concrete than very coarse sand or sand that does not have enough of that fine material. As most of you know, there have been tests in which clay has been added to sand for concrete and for mortar, and the tests have shown a pretty thorough waterproofness obtained by such a mixture. Of course, there is danger in any such natural or artificial material that you will not get a thoroughly uniform mixture; but let us be a little careful how we specify too coarse a quality in sand and how we shut out all the fine material.

Mr. Kinney:—It seems to me that Mr. Larned's suggestion that a reduction be made to 70 per cent of the strength of Ottawa sand obtained by the same cement is hardly a good one in the case of concrete roads. I do not believe that I have ever had, in my experience, a natural sand which would not, if it was the right kind of sand, show 100 per cent of the strength of Ottawa sand with the same cement. There is a reason for that. A natural sand has an advantage in gradation of size. The Ottawa sand is screened between twenty and thirty meshes and it has not that advantage. Therefore, sand of the same quality as Ottawa sand, having the advantage of gradation of size, should show more than 100 per cent of Ottawa sand strength. And therefore by limiting it to 100 per cent it might be doing an injustice to the natural material, and it seems to me that 100 per cent is a very safe figure, particularly in concrete roads, where we need the very best concrete. Seventy per cent might be all right in some classes of concrete, but 100 per cent ought to be named, I think, in the specifications.

As to the question of the fineness of the material we are using in concrete roads, I believe it is pretty thoroughly accepted that a mixture not leaner than 1 : 2 : 3 should be used. This gives us a very large amount of fine material and there is no necessity for adding any fine material or clay to

increase the waterproofness. Too fine material, on the other hand, has the disadvantage of causing a delay in the hardening of the concrete, which is most objectionable in the fall or early winter. The only advantage I can see for fine material in sand is that it delays the hardening of concrete so that it does not dry out. This, however, is accomplished by the best builders by sprinkling their roads or covering them during the early stages of the hardening process. Therefore, it seems to me there can be no advantage for fine material in the sand.

Mr. Larned:—The question of comparison between the strength of Ottawa sand and bank sand should be considered in connection with the period at which the test is made. It is quite possible that the commercial sand at 3 days may show only 60 per cent of the value of Ottawa sand. At 7 days it may show 80 per cent. At 28 days it may show 125 per cent. Now, what are we testing for? Is it a matter of 3 days or 7 or more days? We hold in our specifications that concrete roads shall not be put into use for 3 weeks. Why not, then, consider the relative strength of commercial sand compared with Ottawa sand at that period?

Mr. Kinney:—My opinion is based on the specifications for 80 per cent at the 3-day period. In the committee report 80 per cent was set for the 3-day test. Of course, the question of the percentage to select is for the committee to decide.

Mr. Wig:—I wish to emphasize the statements made in the report that too much dependence should not be placed upon briquette tests. A very fine sand which will give the highest results in briquettes will sometimes give the lowest results in concrete.

Mr. Thompson:—The only points that have been brought out are the fineness and strength. Prof. Baker is quite right in saying that fine material increases the water-tightness, but that is true only under certain conditions. If you have a rich mortar, such as 1 : 2, to get the strength, you have a much more water-proof pavement than you do with a 1 : 2 mixture containing a lot of fine material. For large work, such as dams, I specify frequently that there must be a large percentage of fine material for filling the voids; but for concrete pavement this fine material is not necessary and is liable to be detrimental.

With reference to the strength, the joint committee on concrete and reinforced concrete in the last report requires 100 per cent sand or else, if it tests lower than this, that it shall have a larger percentage of cement with a limit of 70 per cent as the ratio between bank sand and the standard sand. For large construction we might frequently use sand somewhere between the limits of 100 per cent and 70 per cent; but for pavements, where the question of wear is under consideration, it is necessary to get a high standard if we wish to have good results.

REPORT OF COMMITTEE IV

PREPARATION AND TREATMENT OF SUB-GRADE FOR CONCRETE ROADS

Chairman—IRA O. BAKER
Professor of Civil Engineering, University of Illinois, Urbana, Illinois

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State Highway Engineer, Springfield, Ill.

IMPORTANCE OF PREPARATION OF SUB-GRADE

The Committee calls attention to the fact that defects in the subgrade of a concrete road, or the improper preparation of it, may neutralize or nullify the care given to subsequent stages of the construction.

The fundamental requirement of the subgrade is that it shall at all times be of uniform density, so that it will not settle unevenly and cause cracks in the concrete surface. Some engineers apparently believe that it is not necessary to take as much care in preparing the subgrade or foundation of a concrete pavement as of other forms of roads having an artificial surface, because the concrete slab will act as a bridge over any soft streak or low spot in the foundation; but the Committee is of the opinion that this is a mistake. The strength of a plain concrete slab in acting as a beam to carry the load over a low spot or soft place in the foundation is very slight; and it is so easy to remove the low place or soft spot as not to justify the dependence upon the beam action of the concrete. Any uneven settlement of the foundation of a concrete pavement is nearly certain to cause a crack. With some forms of pavements a crack in the surface will heal under traffic; but a crack in a concrete pavement not only can not heal under traffic, but will continually enlarge. There is no part of the work of the construction of a concrete pavement that is more worthy of intelligent care and painstaking labor than the preparation of the subgrade; and the slight additional cost necessary to insure good results is abundantly justifiable.

NEW PAVEMENT ON OLD ROADBED

If the concrete pavement is to be constructed upon virgin soil, that is, if it is not to be constructed on an old roadbed, the precautions usually taken, which are described in the specifications to follow, are sufficient to secure a reasonably good foundation. But if the concrete pavement is to be constructed upon an old roadbed of any kind, either an earth or a broken-stone or gravel road, great care must be taken in preparing the subgrade. The old roadbed is likely to be more compact in the center than at the sides; and consequently there is danger that the concrete pavement will settle more at the sides than at the center, and therefore will crack longitudinally. Further, it is likely that the traveled way of the old road will not at all places be central under the new concrete pavement, and consequently the latter will *settle unevenly* and crack.

When the subgrade is an old roadway, it is not sufficient to roll the sub-grade longitudinally, since the roller is likely to balance upon the more com-pact central core, and therefore not consolidate the soil at the side of the old oadway. It is not necessary to attempt a detailed description of the method of overcoming this difficulty; but the engineer should be alert to determine whether this condition obtains, and when it does occur he should take the necessary precautions to secure a thorough consolidation of all parts of the new roadbed. It may be necessary to add material at the side of the more compact central core of the old roadway. In extreme cases it may be necessary o loosen the old roadbed by spiking or scarifying, and then harrow it, and inally consolidate the entire new roadbed with the roller. The Committee lesires to emphatically assert that the need of care in this matter is not maginary, and that such conditions do really occur in actual practice.

DRAINAGE

The drainage of the roadbed of a concrete pavement is of vital importance. f the subgrade is not well drained, there is danger that after the concrete laid, the drying of the soil under the edges of the concrete may permit the avement to settle and thus cause longitudinal cracks on the surface. Further, the subgrade is not well drained, there is a possibility that the frost may ft the edges of the concrete roadway and cause a longitudinal crack, at ast on the lower side and possibly also upon the upper surface of the con-rete. It is hardly possible in a report of this character to give detailed structions for the adequate drainage of the roadbed for all kinds of soil nd for all conditions, but a few remarks may be permissible.

If the soil is sandy, there is a probability that the natural under-drainage sufficient for the purpose.

Where under-ground water is likely to be present, it is necessary also lay a line of ordinary farm tile on one or both sides of the pavement. The le should be at least 4 or 5 inches in diameter, and should be laid 2½ 3 feet below the surface. The tile drain should have sufficient fall to ree itself promptly and fully. It is better to lay the tile outside of the dge of the concrete slab than under it. Some engineers put a layer of oarse gravel or broken stone immediately above the tile to facilitate the ntrance of the water into the tile; but such precautions are unnecessary xcept to aid the entrance of surface water directly into the tile. Ground ater always enters the tile from below.

If the soil is only moderately retentive, it is recommended that a shallow ongitudinal ditch be constructed just outside of the edge of the con-rete slab. The ditch should extend about 8 or 10 inches below the urface of the roadbed, that is below the bottom of the concrete slab; and hould be filled with coarse gravel or broken stone. From this longitudinal itch short transverse ditches should be dug across the shoulder to the ditch t the side of the roadway. These transverse trenches should have a grade ufficient to permit them to carry the water promptly and fully to the side itch. In particularly retentive soil, these transverse trenches should not be laced more than 50 feet apart. On level stretches, these transverse ditches hould be practically at right angles to the direction of the road; but if the oad is on a grade, these trenches should make an acute angle with the road-ay, the amount of this angle depending upon the grade of the road. The loping of these lateral trenches down hill makes it unnecessary to have the itches at the sides of the *roadway* as deep as would otherwise be required.

These lateral ditches should be filled level full with broken stone or coarse gravel to a point at least a little beyond the outer edges of the shoulders and preferably nearly to the bank of the ditch at the side of the roadway.

SPRINKLING THE ROADBED

Possibly the following item is more properly included in the instructions for laying the concrete; but it is mentioned here in order that it may not be overlooked. Before the concrete is placed, the roadbed should be thoroughly saturated with water. This precaution is particularly important if the ground is dry or the soil is sandy.

SPECIFICATIONS FOR SUBGRADE

It is assumed that the following specifications for the preparation of the subgrade are accompanied by a complete set of specifications, the general clauses of which define what shall be regarded as included under the general term plan or plans; and it is further assumed that the general specifications have the usual clauses as to the mutual dependence of the plans and the special specifications, and also as to omissions and conflicts between the plans and the specifications.

PLANS AND SPECIFICATIONS

The plans, profiles, cross sections, and grade sheets referred to herein are those prepared by .... and approved by the .... Highway Commission on .... 191..; and the same are hereby made a part of this contract, and shall be held to cover any and all work needed for a complete and workmanlike job. It is understood that no advantage will be taken of discrepancies found in said plans, profiles, grade sheets or specifications.

CLEARING AND GRUBBING

The Contractor shall thoroughly clear all bush, trees, and perishable matter for a width of 25 feet on each side of the center line of the proposed roadway, and remove the same from the limits of the right of way.* The road shall be thoroughly grubbed for the full width of the excavation, and no stumps or large roots shall be left within these limits except when a fill of more than 5 feet is called for on the plans, in which case all stumps shall be cut off to within 12 inches of the original ground level. Stumps on the cleared portion not within the grubbed limits, shall be cut off not more than 2 feet from the ground.

The Contractor shall notify the Inspector [or the Engineer in charge, or the Highway Commissioner, or other officer, as the case may be] when the clearing and grubbing is completed; and the moving of earth on any section of road shall not be commenced until the grubbing has been accepted by him as completed.

EXCAVATING AND EMBANKING

The Contractor shall grade the roadbed in conformity to the profile shown on the plans. When the material from the cuts is not sufficient to make the fills, the Contractor shall furnish the necessary extra material to bring the fills to the proper width and height. Excess material from th

*If the pavement is to be more than 15 feet wide, this quantity is to be proportional greater.

cuts shall be used to widen the fills as directed by the Inspector [or the Engineer in charge, or the Highway Commissioner. or other officer, as the case may be].

If the natural lay of the ground is such that after the grading is completed, there are sumps or pockets which hold water, or if such sumps or pockets are made during the progress of the work, the Contractor shall dig, without extra compensation, such ditches within the right of way as shall thoroughly drain these sumps or pockets. Water standing in the side ditches will be regarded as evidence of the non-completion of the contract. Ditches dug beyond the limits of the right of way will be paid for as extra work, except when they are specifically designated on the plans.

When the earth work is completed, the dimensions and the slopes in cuts and fills shall be those given on the plans; and the edge of the roadway shall be the distance from each stake and also the distance above or below the top of each stake given in the Grade Sheet forming a part of the plans.

The side slopes in cuts and fills shall be neatly and smoothly trimmed to the slopes given on the cross sections for the particular class of soil.

When presented for acceptance the roadbed shall be neatly smoothed up from end to end; and shall have the line, grade, and cross section shown on the plans. The road shall be free from rubbish and surplus material.

ROLLING THE ROADBED

The roadbed shall be considered as that portion of the road upon which the concrete is to be placed. The roadbed shall be rolled with a 3-wheeled self-propelling roller weighing not less than 10 tons, until every portion of it is firm and hard.

When the natural roadbed is so sandy that no consolidation of the soil can be secured, the rolling may be omitted. If soft spots occur in the subgrade, they shall be dug out and the soft material shall be replaced with good dirt or other material which will consolidate under the roller.

DISCUSSION

Professor Baker:—The committee has attempted to emphasize the importance of the preparation of the subgrade. It is probable that some of us differ with the committee as to one or two statements. For instance, the committee thinks it unwise to depend upon the strength of the concrete slab to bridge over weak places. The committee is ready to believe that there are times that the slab has bridged over weak places; but the instances are so unusual that the committee is of the opinion that it is unwise to count upon it.

Further, the committee has some information to the effect that some think that cracks are not likely to occur in concrete pavements as in other places because of the strength of the concrete. The committee has asserted that cracks are exceedingly detrimental in concrete pavements because they will not heal. The committee has drawn a report on the expectation of trying to build a concrete pavement that shall not crack.

Further, the committee has made some comments about the preparation of the subgrade over an old roadbed and stated some of the precautions that shall be taken. A good many longitudinal cracks are due to a hard backbone or core in the center of the old roadway. Suggestions are made to prevent that difficulty.

The committee has attempted to emphasize the importance of drainage and of thorough under-drainage. If the ground is only partially retentive the committee believes that a channel under the edge of the concrete should be prepared and should be filled with broken stone to intercept any drainage water that may flow from the crown of the concrete slab to the edges of the slab and settle under the side and the channel should have drainage to the side ditches by means of similar stone filled trenches.

If there is any likelihood of underground water being encountered the committee is quite sure that it will ordinarily pay to lay tile. The committee says that the tile shall not be less than 4 or 5 inches. Some of the committee thought that the tile should be much larger. The committee is informed of places where smaller tile has been used and has not accomplished the purpose. The difference in cost of laying is nothing and the difference in first cost of purchase is very slight as between 4 and 5 inch tile and 5 and 6 inch, or even 7 or more. So the committee has selected a tile which it believes is the absolute minimum.

Mr. K. H. Talbot:—The report of the committee covers the subject of Preparation and Treatment of the Sub-grade with special reference to the importance of careful workmanship and supervision in this part of the construction of a satisfactory concrete pavement. There are, however, a few suggestions that I would like to bring to your attention in connection with this report. These suggestions have to do primarily with the conditions as they are found in that portion of the country lying east of the Ohio-Indiana line and have been called to my attention by inspection of roads in that territory.

In the second sentence in the second paragraph of the report it would possibly be better to change the wording to read: "Some engineers apparently believe that it is not necessary to exercise the same care in preparing the sub-grade or foundation of a concrete pavement as is given to the preparation of foundations for other types of improved roads, believing that the concrete slab will bridge soft places or low spots in the foundation; but the committee is of the opinion that this is a mistake."

In the next to the last sentence in the same paragraph, would suggest the substitution of the word "some" for "most," making the sentence read as follows: "For some forms of pavement a crack in the surface will heal under traffic, but a crack in a concrete pavement not only cannot heal under traffic, but will continue to enlarge."

The paragraph entitled "New Pavement on Old Roadbed" should in my estimation be changed to recommend that old road material should always be scarified and re-distributed and rolled, for if the material from the old road is sufficiently smooth and uniform to make a good sub-grade for concrete without scarifying, it is very likely that it is sufficiently good to be used for at least a short time, and if it is not in such a condition it will be impossible to get a first class foundation for the new road surface. On hillside work where it is necessary to widen the road and where the slope is such that it will prove difficult to construct a fill in such a manner that it will hold to the old embankment, it may be necessary to place the metal partially on the old road and partially on the space made available by cutting on the upper side and to widen the earth shoulders on the lower side sufficiently to make the road of the required overall width.

The question of drainage on side hill construction should be given consideration in this report. The slope of the strata will determine the amount of care and money that must be expended on sub-drainage and secondary ditches and will have a large bearing on the possibilities of slides affecting

the construction and maintenance of the road. The surface water may be taken care of under certain conditions by cutting a ditch above the road and leading the water to an outlet, while that falling between this ditch and the uphill shoulder is carried by the shoulder ditch to satisfactory outlet. Sub-drainage may be taken care of by French drains or tile drains laid on the uphill side of the road and by transverse drains or culverts at such places as will insure the carrying away of the water with sufficient rapidity to keep the sub-grade dry.

The Maryland State Highway Commission found on the road between Elkton and North East that the sandy sub-grade, which was on a considerable slope, would wash badly, and overcame this condition by placing concrete breakers from the concrete road to the edge of the embankment. The top of each breaker was slightly above the bottom of the one next uphill. This construction resulted in the water depositing the sand which it carried above each breaker and the ditch was thus kept clean without appreciable wash.

On page 3 the suggestion has been made that transverse French drains on low gradients be placed perpendicular to the line of the road. In this connection it might be suggested that in order to most effectively take care of the sub-drainage, all under drains be placed in the form of a "V," as such a drain will serve to keep more sub-grade dry than will one placed directly across the road.

In order that concrete may have a uniform foundation the surface of the stone drain should be covered with clay, loam or sand. If this is not done there is danger of mortar from the portion of the concrete immediately above the drain running into the voids of the stone, thereby weakening the pavement at that point.

It would seem that the clearing of the roadway for 25 feet on each side of the center line as suggested by the committee is unnecessary in many instances and especially on hillside work in rough country. This would require the grubbing of all shrubbery and trees beyond the fence lines on some roads and for a considerable distance up and down the hill from the edge of the road, resulting in increased wash of the surface due to being unprotected.

Too much stress cannot be laid on the matter of satisfactorily widening fills. The railroad practice on this character of work has been to plow the sides of old earth fills or excavate steps on low fills. All vegetable matter should be cleared away and no logs or rubbish allowed in the material for the fill. The concrete road surface under such conditions as this should not be placed until the grade has passed through at least one winter.

Mr. Warren:—There are two important things that should be recognized by road designers. One is this: "Any uneven settlement of the foundation of a concrete pavement is certain to cause a crack." That means something. One of the reasons we are here is to eliminate these cracks and get an ideal pavement. We must realize in the beginning that something must be done to eliminate cracks. A crack in a concrete pavement not only cannot heal under traffic but will continually enlarge. Maintenance of that crack will increase each year. The mere fact that the maintenance of these cracks has been comparatively light for the first few years is not any reason why we will not have future maintenance. The crack is a condemnation of the design that we have used. We should not have any cracks whatever in pavements that are no older than the pavements we have today.

The committee has shown that if vertical movement takes place there are certain to be cracks. The remedy they offer for the prevention of cracks, and that remedy has not been wholly a success, is the draining of foundations. And in spite of the precautions for drainage we are often getting cracks where present specifications are followed.

Why do our pavements crack? For this reason: It is absolutely impossible to prevent the soil from absorbing moisture and causing vertical movement by swelling. In other words, you can take a 16-foot slab or a 30-foot slab and lay it right here on this floor just as it stands today, without any vertical movement at the sides, and you will not have any cracks in your slab. But when you lay a 16-foot slab on a road and it is subjected to all these causes, the action of frost, swelling when it absorbs moisture, setting it over an old roadbed, you will find vertical movement, in spite of the tile or other forms of drainage used. It has been my experience in this part of Illinois that when spring comes and the ground is covered with water the concrete is soaked and saturated all through. You may have tile out on the edge, but as soon as the rain comes the water will get right under the center of the pavement.

Now here is the question: Is it possible to absolutely get this moisture distributed to prevent the swelling of the subsoil? Is it possible to eliminate vertical movement? If you have no vertical movement you will have a slab that is going to act as a beam, or else a slab that will rise up and down. Are you going to design it as a beam, or let it crack? There is the question. It is absolutely necessary to design a slab for strength to resist this vertical movement, or in other words, a slab that will act as a beam across the roadway. Now that is what you have unless you get that movement. This is not theory. Look at the pavements laid. We have cracks all over the country to look at. Now those cracks come from vertical movement. If you cannot get away from vertical movement, design a slab that is going to stand the movement. It is true when we stop to realize it that the object of all these discussions is to eliminate cracks. If we can eliminate these cracks we have done something that we can be proud of. If it weren't for the cracks concrete would be the ideal pavement. An ideal pavement is a pavement that is durable. Can you tell me that a pavement is durable when it has cracks in a big percentage of the slabs? The cost of maintenance for the first 2 or 3 years amounts to nothing. If you take the records of the county in Michigan where these pavements have been laid and see the number of cracks they have had in the first 3 or 4 years can you tell where those cracks are going in 30 years? Is it worth while to eliminate them? All we have got to do is design a slab that will withstand vertical movement. Removing water out of your foundation according to present methods will not do it. We must have an ideal design.

This road proposition is a big one in this country and if the engineers want the best—and that is the concrete pavement—they must get a pavement without cracks. Concrete is a pavement that is low in first cost and one that is easily cleaned. Concrete has everything that goes to make up the ideal pavement except perhaps durability.

You have a sample over in Michigan of the finest quality of work that any engineer can ask for, and yet you have occasional cracks through the center of the pavement. I built a pavement in my town of a 1 : 1½ : 3 mix that has cracks. We have them all over Illinois with 1 : 1½ : 3 mixes and ronger with the finest quality of workmanship and materials, yet with cracks.

Evidently it is worth while to eliminate cracks and get an ideal pavement. Then design a slab that will stand the vertical movement. If reinforcement is necessary and you can get it economically, get it. If it takes an increased thickness of concrete and you can do that economically, do that. If there is a better sand, or a better way of preparing it than is the present practice, use that.

We do not want to stand back of a pavement that is subject to wide criticism. We can't stop vertical movement now because we can't remove the moisture, and our theory on that is wrong. What we must do is to design a slab to stand that vertical movement. When that is done we have got the ideal pavement. The designing of such a slab is worthy of thorough investigation.

Mr. Hewitt:—We have about 60,000 square yards of pavement in our town which is two years old this coming season. I inspected this pavement the other day for longitudinal cracks. We have practically no longitudinal cracks in the pavament. This pavement was laid on a subgrade in a heavy clay soil. Illinois hasn't any better clay than we have. The subgrade was crowned to conform to the crown of the pavement. Pavements were all from 24 to 30 and 50 feet wide. They were laid on a cinder foundation about 3 inches thick. There were no expansion joints along the curb. The transverse expansion joints were laid practically every 25 feet, not squarely across the pavement, but at a slight diagonal, in order to remove some of the impact of the traffic. The purpose of the cinder foundation was for drainage and was to provide for the movement of the pavement that causes cracks. The curbs are under-drained, and to show you the necessity for under-drainage, about 12 months in the year they are contributing water to the catch-basins.

I do not know that there is anything further that I have to say about this pavement. We have some bad cracks along the street car tracks that were laid in the center of the pavement. Because of the franchise held by the street car company I could not compel them to build the pavement the way I wanted it built.

Mr. Morse:—If the street car line runs through the pavement it might cause cracks to appear if the slab was divided by the street cars.

Mr. Hewitt:—The street car track runs down the center of the street. The cracks that we have are longitudinal cracks. The street is 32 feet wide between curbs.

Mr. John Wilson:—Throughout the past 3 years I have been very much impressed with the apparent lack of reliable data in regard to the treatment and drainage of clay sub-grades.

It has been the custom in Duluth, where in general we have a dense clay sub-soil, to place a tile drain at each curb line for the purpose of draining the sub-grade as well as to prevent the curb from being displaced by heaving. Some years ago a concrete pavement constructed in this way cracked very badly. The pavement was of the 2-course type, with expansion joints at each gutter and transversely every 50 feet.

The following season a similar pavement was constructed in the same vicinity. In this case, however, the precaution was taken of excavating to a depth of 6 inches *below* sub-grade and refilling with gravel. In addition

to placing expansion joints at the curb a longitudinal joint was placed down the center of the street, the transverse joints every 25 feet across the street. In this case the pavement has cracked but very little.

The question now arises as to whether this improvement was due to the treatment of the sub-base or to the additional joints. It would seem logical, however, that the latter deserves the greater share of the credit, although the former may have contributed to the success of the pavement.

This layer of gravel beneath the base has, rather erroneously I think, been called a drainage course. Now if proper tile drains are placed at the curb and the excavation over these back-filled with porous material so as to effect perfect drainage at the sides, this layer of gravel, except in case of springs under the pavement, can contribute but little to drainage, inasmuch as the pavement is practically impervious. If, however, there should be openings or cracks in the surface of the pavement which will admit water this layer would seem rather to increase the amount of water that could gain access to the base, and in this way be a detriment. And there are cases in the city where I believe that heaving of the pavement has resulted from this very thing.

If the depth of the tile drain at the sides be made a function of the width of the pavement in order that the water plane due to capillarity be kept below the surface of sub-grade, the removal of this material and replacing it with porous material would seem to be a useless expense.

Nevertheless I am not so sure but that a layer of such material as gravel, cinders or sand may serve a useful purpose under a concrete pavement, with clay sub-grade. May it not act as an insulation between the concrete and clay, and thus prevent the latter from freezing with the same intensity as it otherwise would? May it not reduce the frictional resistance between the concrete and sub-base; and lastly may it not insure a more perfect and uniform surface upon which to lay the concrete?

If the concrete is hauled from the mixer to the pavement in carts it is difficult for the inspector to see that all depressions and corresponding ridges caused by the tracking of the cart wheels are properly filled and cut down. This work is considerably simplified if a layer of sand is to be spread over the surface previous to laying the concrete. I have no doubt but that many longitudinal cracks are the direct result of wagon or cart track not having been cared for after hauling material for the pavement over the sub-grade.

We propose to include a 2-inch cushion of sand on top of the clay sub-base and underneath the concrete pavement for the coming season, not for the purpose of drainage, but for the other reasons mentioned. Whether this expense is justifiable or not I am not certain, but I am inclined to think so.

A few questions in regard to this subject which seem unsettled are these:

Does clay expand or contract upon absorbing moisture within certain limits?

To what height will water rise by capillarity in a heavy clay beneath an impervious surface?

And to what depth should a drain at the curb be placed to insure the sub-grade being properly drained?

To what extent, if any, does a porous layer between the concrete and clay sub-base protect the latter from freezing?

Mr. Bowditch:—There are two fundamental principles in the report, *which I believe* will eliminate the most troubles in cracking. The first is,

that any defects in the sub-grade of a concrete road may nullify the care given to subsequent stages of construction. The second is, that the sub-grade shall at all times be of uniform density so that it will not settle unevenly.

I wish to add a third suggestion which I believe is of equal importance. I believe that there should be a flat sub-grade beneath the concrete pavement. If we have a crown in the sub-grade that is hard and unyielding, the passing of two heavy trucks down opposite sides of the pavement at the same time will tend to make the pavement crack. By building on a flat sub-grade we can lay a pavement 4½ or 5½ inches thick at the outside edges and can get our crown by additional thickness of the concrete in the middle of the road.

Mr. F. P. Wilson:—In Iowa we have a clay that is in quality like that of Illinois and Ohio. In 1910 I constructed a roadway 1 mile in length and 40 feet in width on clay subsoil. After the sub-grade had been prepared it was thoroughly compacted with a steam roller. Along the curb on each side, 18 inches from the curb and 18 inches below the sub-grade, I dug a trench and laid 6-inch tile parallel to the curb on each side of the street, running this drain tile into the manholes at the street intersections. At different intervals from 25 to 30 feet apart, extending from the drain tile in the gutter to the center or crown of the street, I also laid drain tile 4 inches in diameter, 16 inches below the sub-grade. These trenches were filled with hard-burned cinders. In December a delegation of gentlemen from Montana visited my city and I took the covers off these manholes and found the water trickling into the manholes. That pavement has not a longitudinal crack in its entire surface.

Mr. Gillette:—There is one practice that has not been mentioned here which is used quite extensively in the state of California, namely, in treating sub-grades to excavate or plow to a depth of 6 inches below the proposed elevation of the sub-grade. The purpose is to loosen all the material, harrow it, cultivate it until it is comminuted into small particles. Then the sub-grade is rolled with what is called a rolling tamper, whose projecting lugs reach down to the bottom of the plowed soil and start packing the soil toward the bottom, gradually working toward the top, until the tamper rides on the completed hard surface of the road. Another method which has more recently been introduced is to excavate entirely 6 inches of earth, throw it up on the side, and then throw it back in ½-inch and 1-inch layers and roll it with a steam roller. In that way, a perfect, uniformly compacted sub-grade is secured.

Professor Talbot:—I call your attention to conditions that prevail in Pennsylvania. I think the same conditions prevail in Vermont. We have there a condition of side hill work, where it is practically impossible to build a road without widening the existing road. Sometimes there are 40 or 50 feet to the place where the slope stakes must be set. If such stakes were set at the bottom of the fills it would usually be necessary to excavate on the up-hill side and place the pavement partially on the old roadbed and partially on the cut rather than on the fill. I have noticed several roads where they have tried to place them on the fill, and the fill always got away from them. In that connection I would like to call your attention to the necessity, where a fill is widened, of either stepping down the old fill or else plowing the surface of the slope of the fill, as has been practiced in railroad work.

The question of grading on side hill work has not been touched. It seems to me that we have a large number of conditions, such as the slope of the strata, that will determine whether or not our road will be a wet road or a dry road; and if the strata are sloped toward the road so as to have an up-hill slope, this condition should be taken into consideration. Under such conditions, it would seem advisable to go up-hill some distance and place a secondary ditch to catch the surface water and turn it away from the road, and then put the regular ditch slightly above the main road on the ditch line of the road to take care of the surface water between the two ditches and such ground water as might come out. Then an under-drain should be used on the up-hill side and a sufficient surface drain used to carry the water across the road and into the ditches.

Referring to the use of the sub-base and the placing of concrete, we get into the condition of the strata and ground water. It seems to me that our drains would be more effective than a sub-grade. Let us use this floor as an example. If a concrete pavement were placed on the floor the water must move longitudinally to the pavement until it gets to the edges to get out. If we use a cinder bed or gravel base the water will move longitudinally along the sub-base until it gets to the outlet and then be carried out. The result would be that our sub-base will be a drain, not a protection to the pavement, and will be a drain which will always be more or less wet, and which in case of freezing will be more disadvantageous than clay. I believe that drainage on the side, in connection with these drains, is more effective than the gravel or cinder sub-base.

REPORT OF COMMITTEE V

REINFORCEMENT OF CONCRETE ROADS

Chairman—THOMAS H. McDONALD
State Highway Engineer, Ames, Iowa

HENRY E. RIGGS
Professor of Civil Engineering, University of Michigan, Ann Arbor, Mich.

RICHARD L. HUMPHREY
President, American Concrete Institute, Philadelphia, Pa.

The ideal pavement should have a surface of a character that will prevent slipping, free from waves and without joints or cracks. Of the paving materials available, concrete more nearly meets this condition than any other. Since concrete has little tensile strength, it is inelastic and cracks may develop from the following causes:

a. Changes in temperature.
b. Variation in the percentage of moisture in the concrete.
c. Defective foundation.
d. Improper drainage.
e. Insufficient thickness in slab to carry the traffic.
f. Faulty construction.

It is necessary, therefore, in a pavement properly designed and constructed, to minimize the cracks resulting from the above causes by imbedding a reinforcement in the concrete which will so distribute the tensile stresses as to prevent formation of larger cracks.

Cracks of any character are objectionable in concrete roads and any preventative deserves consideration. When a pavement is properly reinforced objectionable cracks cannot develop. Such cracks are always objectionable from the fact that they become filled with dirt or other foreign matter and the edges will spall off and create rough spots in the road, which can never return to its original condition.

a. Reinforcement for temperature changes

The effect of an increase of temperature is to increase the length or expand the concrete pavement and a decrease in temperature is to decrease or shorten the pavement. In the latter case, assuming that there is no reinforcement, cracks will form at more or less regular intervals. These cracks will occur at right angles to the direction of the line of the roadway at intervals of 25 or 50 feet. Since concrete and steel have practically the same coefficient of expansion, namely, 0.0000055, the two materials will expand or contract equally under temperature changes, but the presence of the steel prevents the entire effect from being localized at one point and distributes the stress over a considerable space, thereby preventing any large cracks. The common practice is to provide joints in concrete pavements that are not reinforced at intervals of from 25 to 50 feet. Through the use of reinforcement

the spacing of these joints may be very materially increased and it is possible to so reinforce a concrete road as to render joints either wholly unnecessary or at extremely long intervals. By properly reinforcing the roadway the thickness may within limits be decreased, thereby increasing the serviceability of the roadway and decreasing the cost.

b. Variation in the percentage of moisture in the concrete

Experiments seem to indicate that concrete expands when thoroughly wetted and shrinks when thoroughly dried out, and that the change of length due to this cause is about 0.005 per unit of length. Experiments seem also to show that expansion and contraction, due to the variable content of moisture which results from extreme wet or dry weather, produces cracks in the concrete, unless the pavement is sufficiently reinforced to distribute these stresses in the manner described under reinforcement for temperature changes. Further proof is desirable, however, before this fact is accepted, and further experiments are needed to show the effect of density and mass on the per cent of moisture in concrete. It seems likely that a very dense mass of concrete of some thickness will only be superficially affected and the mass will not be materially affected.

c. Defective foundation

Concrete pavements laid on a subgrade which contains fills or other soft places which are liable to settle, thus leaving the concrete pavement without proper support, will result in cracks unless the pavement be sufficiently reinforced to distribute the load over a larger area, thereby bridging over these soft places where there has been settlement in the subgrade.

d. Improper drainage

It is essential that the roadway shall be properly drained; otherwise the collection of water in the subgrade will tend to produce settlement or other disturbance and result in the cracking of a pavement without reinforcement.

Concrete pavements when reinforced will so distribute the load over these soft spots as to reduce the cracking to a minimum.

e. Insufficient thickness of slab to carry the traffic

Where the traffic on the road is very heavy it frequently happens that the concrete un-reinforced is insufficient in thickness to support this load, especially if the subgrade is not of suitable character, and both longitudinal and transverse cracks are the result. Settlement in the foundation under heavy traffic will produce objectionable longitudinal cracks. The introduction of reinforcement in the pavement distributes the load and thereby prevents the formation of these cracks.

f. Faulty construction

These same cracks and imperfections appear when faulty construction occurs, which is generally the result of improper design or supervision, or both.

The percentage of reinforcement required in a concrete roadway will depend on the nature of the traffic, the conditions in the subgrade and the range of temperature and the variation in percentage of moisture.

This committee is of the opinion that all concrete roadways should be reinforced with a fabricated reinforcement and undoubtedly, regardless of *width, a reinforced* concrete roadway is superior to any other form of road;

that through the proper use of reinforcement the cost of a concrete pavement may be decreased and the cracks so distributed as to be practically invisible, thereby preventing objectionable breaks in the surface and decreasing the cost of maintenance.

The amount of reinforcement to be used should be determined by an engineer familiar with the local conditions. The range of temperature and the percentage of moisture varies with each locality, as does the character of the traffic over the roadway; it is evident, therefore, that each roadway must be studied to suit these conditions.

The soil composing the subgrade will vary in different localities. It will be found advantageous and necessary to use additional reinforcement where the subsoil is of an inferior character or the road is on a fill, or any condition where there is likely to be considerable settlement in the subgrade.

Your committee, therefore, is unable to prescribe the exact amount of reinforcement required since it will vary with each road. In general, however, the reinforcement should be about 1/10 of 1 per cent per foot of width.

REPORT OF COMMITTEE VI

METHODS AND COST OF REPAIRING AND MAINTAINING CONCRETE ROADS

Chairman—EDWARD N. HINES
Chairman Board of County Road Commissioners, Wayne County, Detroit, Mich.

J. S. McCULLOUGH
City Engineer, Fond du Lac, Wis.

F. P. WILSON
City Engineer, Mason City, Iowa

In preparing and presenting a report on Methods and Costs of Repairing and Maintaining Concrete Roads, we assume that it has to deal with the metaled surface rather than the shoulders, ditches or sides, and with this end in view we are presenting the individual experience of the members of your committee to whom this subject has been assigned.

With the opportunity to make a field study, having partly in charge at least the many miles of concrete roads in Wayne County, some of which are now in their fifth year of service, it seems to me that the actual experience and methods followed are of more value than any laboratory experiment or theoretical discussion. We, in Wayne County, have followed two methods in maintaining the concrete roads, the first of which consists in filling the open expansion joint on the roads first built before the development and use of the armor joint, and in the filling with a mastic such longitudinal and transverse cracks as have developed.

A crew consisting of 7 men and a team, provided with a tar kettle, is utilized for the work. The foreman is paid \$5.00 a day, the team and driver \$5.00 a day, the "tar man" \$3.00 a day, two laborers at \$2.50 each and two laborers at \$2.25 each. The tools used consist of two wire bristle brooms, a wheelbarrow, a couple of shovels and a tar bucket with a round spout. Tarvia X is now used exclusively. A lighter grade was first tried out, but did not give such permanent results as the heavier grade. Two men are utilized to sweep all cracks clean with the wire brooms, after which the man with the tar kettle fills the cracks with the tar which is heated to about 225 degrees Fahrenheit. An excess of tar is poured in so that it extends an inch or so beyond the edge of the crack. It is then allowed to stand in the crack for a few minutes to prevent it from "bubbling" out in case the sand is wet. The sand, which should be dry and coarse, is spread with a shovel over the crack and into the tar, and the whole is left for traffic to iron out. The excess tar and sand is worn away rapidly, leaving a smooth, even surface, over which no jolt is apparent in passing either with a horse drawn or motor driven vehicle. This method of repair prevents the edges of the concrete from spalling and chipping, and no water can get through to the subgrade to freeze and heave in cold weather.

The work is preferably done on hot, dry days. It has been suggested us that the better time to handle this work would be in the late fall wh- the cracks would be open the widest due to contraction, but the results have secured in the summer months have been so satisfactory that we ha..

not tried out the latter plan. The small pit holes which are due simply to some foreign substance getting into the concrete like clay, wood or some fragment of inferior rock which might chance to be a part of the aggregate, are treated in the same manner. As to the cost of this method, we desire to present a verbatim report of the engineering staff, Messrs. George A. Dingman and George F. Key, to the Board of County Road Commissioners:

Michigan Ave. Road........	Tar....20 bbl.			$120.00	
17 miles	Labor..10 da. [illegible]			225.00	
	Sand...18 yds. at			36.00	$381.00
Grand River Road..........	Tar....14 bbl. at		6.	84.00	
10 miles	Labor.. 6 da. at		22.50	135.00	
	Sand... 8 yd. at		2.00	16.00	235.00
Gratiot Road..............	Tar.... 3 bbl. at		6.00	18.00	
1½ miles	Labor.. 2 da. at		22.50	45.00	
	Sand... 4 yd. at		2.00	8.00	71.00
Jefferson Road............	Tar.... 6 bbl. at		6.00	36.00	
1¾ miles	Labor.. 2 da. at		22.50	45.00	
	Sand... 4 yd. at		2.00	8.00	89.00
Van Dyke Road............	Tar.... 5 bbl. at		6.00	30.00	
2⅛ miles	Labor.. 1½ da. at		22.50	33.75	
	Sand... 4 yd. at		2.00	8.00	83.00
Mt. Elliott Road...........	Tar.... 3 bbl. at		6.00	18.00	
1½ miles	Labor.. 1½ da. at		22.50	33.75	
	Sand... 4½ yd. at		2.00	9.00	60.75
River Road................	Tar....10 bbl. at		6.00	60.00	
7 miles	Labor.. 5 da. at		22.50	112.50	
	Sand...12 yd. at		2.00	24.00	196.50
Eureka Road..............	Tar.... 4 bbl. at		6.00	24.00	
4¼ miles	Labor.. 2 da. at		22.50	45.00	
	Sand... 4 yd. at		2.00	8.00	77.00
Wayne Road South.........	Tar.... 1 bbl. at		6.00	6.00	
½ mile	Labor.. ½ da. at		22.50	11.25	
	Sand... 1½ yd. at		2.00	3.00	20.25
Woodward Ave. Road.......	Tar.... 5 bbl. at		6.00	30.00	
2¼ miles	Labor.. 2 da. at		22.50	45.00	
	Sand... 6 yd. at		2.00	12.00	87.00
[illegible] miles.....................	Total.....................				$1,300.50

A percentage was added to cover engineers, inspectors and the depreciation of machinery and building and other "overhead" charges, totaling approximately $1,450. (See page 39, Seventh Annual Report.) This report covers the fiscal year of the Board from October 1, 1912, to September 30, 1913, inclusive. The greater part of this mileage was treated for the first time. Once a year is often enough to go over the work and touch it up here and there, as we have found by experience that the bulk of the repairs previously made is intact.

We have not had as good success in treating the entire surface of a road where the concrete from any cause has not stood the wear. One-half mile of concrete on Fort Road, built by Porath & Son, about 800 feet on Grand River Road, built by the Owosso Construction Company, and 1¾ of a mile on Gratiot Road, out of the 80 odd miles of concrete road in Wayne County, are not up to the standard of the balance of the construction, and they have been surfaced with Dolarway, a special grade of Tarvia and Tarvia X. The surfaces of Fort and Gratiot Roads were both rough, having been built in cold weather, and opened for traffic before the concrete had thoroughly hardened. Fort Road was surfaced by the contractor before the Board would accept the road and make the final payment. It carries a fairly heavy mixed traffic, not as great, however, as either Grand River or Gratiot Roads. A special grade of Tarvia was used, furnished by the Barrett Manufacturing Co. The road was first swept by a street sweeper which was followed by men with wire brooms. About ½ gallon of bitumen to the square yard was used, and the whole covered with coarse sand and rolled with a 10-ton roller. This repair was made early in the summer and was not touched in any manner for a period of 2 years. By this time it had scaled off in spots quite badly, and was gone over again in the summer of 1913, using Tarvia X and a washed roofing gravel about ¼ inch in size. We have no record of what the first cost was to the contractor, as we paid nothing for it.

Gratiot Road was surfaced at cost to us by the Dolarway people in the spring of 1912. By the summer of 1913 about half of the original coating had scaled off, at which time we patched it up, using a special grade of Tarvia and Tarvia X. The Tarvia X has given the better result to date. Washed roofing gravel was used with the bitumen. This work was also rolled with a 10-ton roller. Gratiot Road carries an average traffic of over 1,000 vehicles a day. (On the last count made one week in August and one week in September the average traffic per day was 1,210, of which 36 per cent was motor traffic and 64 per cent horse drawn vehicles.) The surface of the road is wavy, and we have found it necessary to go over the work two or three times during the summer, touching up small spots here and there where it had scaled off. The cost of the work done by our Board is in the neighborhood of 9 cents a square yard.

EDWARD N. HINES.

METHODS OF REPAIR OF CONCRETE PAVEMENTS, FOND DU LAC, WISCONSIN

The repairs on our pavements to the present time have been taken care of entirely by contractors who built the pavements, and is part of their obligation, under our contract. The pavements are guaranteed for 5 years, and our oldest work was 5 years old this past summer.

The method of repairing cracks is similar to that in use in Wayne County. Both Asphalt and Tarvia have been used, but we find Tarvia gives the better results.

We have had some work of replacing pavement cut out for installing service pipes, such as sewers, gas, and water, also a long piece for installation of telephone conduit. The telephone work was done by contract by the telephone company; all other repair of such excavations has been done by the city through its repair gang.

The excavation is made by the public utility after receiving permit from the Board of Public Works. Excavation is required to be back filled with gravel, sand, or crushed stone to sub-grade of pavement. Our men then proceed to trim the edges of hole so walls of cut are as near perpendicular as possible. Mixture same as original pavement is then put in and finished same as original work. Traffic is kept off until concrete is hard. Where the work has been carefully done we have had good success in making such patches. The cost will not exceed that of replacing brick that are cement grouted and, in fact, what records we have would indicate that concrete pavement patches can be replaced more cheaply than the brick.

J. S. McCULLOUGH.

EXPERIENCE AT MASON CITY, IOWA

Mr. Hines' experience as given in his paper on the topic, "Methods and Costs of Repairing and Maintaining Concrete Roads," I have carefully read, and the contents of the same describe methods I have used on the maintenance of cement city streets and I consider them most practicable and economical methods for maintaining a concrete road or pavement. If the roadway or pavement is given a careful inspection at least twice a year and all the defects filled with Tarvia X and coarse, clean sand, free from loam or clay, put on the road or street when the same is perfectly dry, clean and free from any foreign substance, when the temperature of the weather is at least 80 to 90 degrees Fahrenheit, good results will follow and the concrete road or pavement will last indefinitely and the cost of maintenance will be reduced to a minimum.

It has been my experience as an engineer during the past 6 years in the design and construction of approximately 300,000 square yards of cement paving for city streets that to reduce the cost of repair and maintenance to a minimum, the following rules should be carefully carried out in the construction of cement streets or roads:

1st. To have the sub-grade thoroughly drained, where it is necessary, by using farm drain tile not less than 4 inches in diameter, after which the sub-grade should be rolled and compacted with a heavy steam roller until it is perfectly solid over its entire surface.

2nd. After the sub-grade has been prepared, great care should be taken to keep it wet, before placing the concrete, as a dry sub-grade draws the moisture from the concrete mixture and is thus harmful.

3rd. Have a first class Portland cement that will pass the requirements of the American Society for Testing Materials.

4th. Have a sharp, clean sand, which does not contain more than 2 per cent of loam.

5th. Have a good hard stone or gravel, free from dust, loam or clay and crushed so that it runs from ¼ inch to 1½ inches in size, 66 per cent of the stone to be the coarser and 34 per cent the finer of the stone aggregates.

6th. The fine aggregates and coarse aggregates should be thoroughly mixed with an up-to-date batch mixer, until all the stone is coated and is of such consistency that all that is required is to level off the mass so that the concrete runs into place, no tamping being required and a dense compact volume is obtained.

7th. Have an expansion joint 1 inch in width left next to the curb on each side of the street, this space to be filled with an asphalt filler. Have transverse expansion joints ½ inch in width left every 37 feet 6 inches at right angles with the curbs, these expansion joints to be protected on either side with steel plates, 2½ inches in depth, ¼ inch in thickness, with a shear member 6 inches in length cut out of the sides of the plates at equal distances and bent at right angles and extending into the concrete, these steel plates to be not less than 15 feet in length. Between these plates place a three-ply tar felt paper especially prepared for the expansion joint.

8th. Finish the surface of pavement with a wood float, made of a coarse grained soft wood, so as to give a uniform rough surface which will give a good foothold.

9th. The curing of concrete pavement is one of the most important features and on it depends the durability and strength. The pavement, immediately after it is laid, should be covered and protected from the sun, and as soon as it is hard enough, should be sprinkled daily and kept wet not less than 8 days.

10th. Concrete paving, where the width of roadway is more than 20 feet between curbs, should be reinforced with No. 7 American Wire, to eliminate cracks or cracking.

11th. A concrete pavement, after it is laid, should be protected and the traffic kept off for at least 3 weeks, so as to give it a chance to thoroughly harden.

12th. To obtain a first-class result in the construction of concrete streets, also to reduce the maintenance of the same to a low cost, every detail as heretofore described must be followed. The methods described I have followed in the State of Iowa and other states in the Northwest in the construction of concrete streets, and the results speak for themselves.

F. P. WILSON.

REPORT OF COMMITTEE VII

SHOULDERS FOR CONCRETE ROADS

Chairman—MAJ. W. W. CROSBY
Baltimore, Md.

E. A. KINGSLEY
State Highway Engineer
Little Rock, Ark.

JOHN H. MULLEN, *Secretary*
Minnesota Roadmakers Association
St. Paul, Minn.

With the almost universal tendency in concrete-road construction to keep the width of the concrete as low as practicable, in order to reduce the first cost (per mile) of the improvement of a road, has come, in many cases at least, a neglect of proper consideration of the matter of shoulders. In many cases the neglect referred to has unquestionably resulted in extravagance and waste in the long run, even if it has secured economy in first cost.

While authenticated records covering reasonable periods and concerning the relative expense for the proper maintenance of road-crusts and of shoulders respectively are not readily available, certain instances of such records (as published concerning Park Heights Avenue, near Baltimore, Maryland*) together with the individual experiences related by many authorities, tend to show that the shoulder maintenance costs may be no inconsiderable part of the total maintenance costs of a modern road, and that it may often be real economy to build the road-crusts wider in order to reduce this annual expense for maintaining the shoulders and thus the total maintenance cost per square yard. From the Park Heights Avenue records above referred to it may be seen that, although the travel over the 24-foot wide sections was 4 times that over the 12 and 14-foot sections, the cost of maintenance per square yard of the road-crusts of the latter was more than twice that of the crusts on the wider sections, and the cost of maintenance of the shoulders on the narrower sections was nearly 3 times that for the shoulders along the wider crusts. Indeed the economy in maintenance on both the shoulders and road-crusts of the wider sections indicates that, in a 10-year period from the date of construction, real economy would have been had by increasing the width of the road-crusts so that nowhere would the latter have been less than 18 feet.

But the subject for consideration is not "The Economical Widths of Road-Crusts" but "Shoulders for Concrete Roads", and after the above specific illustration of the importance of shoulder consideration that of the actual subject may be resumed.

The actual width of the concrete roadway to be built must be determined by the traffic conditions to be expected on the road, and if these are sufficiently heavy to warrant so doing, it will probably be economical often to make the concrete itself wide enough to permit the passing of two lines of traffic wholly on its surface and without any necessity for either of passing vehicles to travel off the concrete onto the shoulder. On the other hand, traffic and other conditions may be such as to permit the greatest economy to be had by making the concrete only wide enough for one line of traffic and allowing the occasionally passing vehicle to travel on the shoulder for the moment.

*Proc. Am. Soc. C. E., Vol. XXXIX, No. 7, p. 1706, etc.

The immediate vicinity of the line of contact between the edge of the concrete and the shoulder material will be found to be the tender region of both the road-crust and of the shoulder. The high rigidity of the concrete road and consequently the greater contrast between such a road-crust and other material usually available for shoulders increase the importance of the careful consideration in the matter.

Where the concrete road-crust is so narrow that vehicles are almost constantly, in avoiding others, passing from the concrete to the shoulder, serious wear of both the road-crust and the shoulder will be found to take place along the region of contact referred to, and this wear is frequently accompanied by the formation of a rut in the shoulder, which holds water in wet weather and thus endangers the foundation of the road. Some of the passing traffic will undoubtedly turn out onto the shoulder further than the rest, but at the extreme outside of the shoulder the travel over it may be so light and infrequent that the natural material there is not strained beyond what might be called "its elastic limit," and there then is no reason, on this account at least, for its replacement at any extra cost.

It will therefore be seen that the selection of the material and methods for the construction of shoulders to a concrete road requires the use of something between the natural soil, at the outside extremes, and the concrete itself; that the choices are determined by local conditions, such as availability of different materials and methods, width of the concrete road-crust, amount of traffic, etc., etc.; and that the wearing abilities or "elastic limits" of the shoulder material at any point should be outside or above the stresses to be expected at that point.

The passage of traffic from the pavement to soft adjacent material can of course be absolutely prevented, and the protection of the edges of the pavement be had by the installation of a raised edging or curb, as in the cases of most streets. The necessary reinforcement of the shoulder where no raised curb is to prevent traffic on it may be had in various ways. One would, of course, be to widen the concrete road-crust to such an extent as to preclude any possibility of traffic going off it. In doing this the center thickness of the crust need not necessarily be preserved to its edges but the thickness may be tapered down somewhat at the outsides. Or this widening (and tapering down in thickness) of the road-crust may be done over a portion of what might otherwise be the shoulder and then the reinforcement continued by the use of macadam or pit-gravel or other materials as may be necessary. Again, the width of the concrete road crust being fixed, the shoulder reinforcement may be had by the construction of pitch concrete, pitch macadam, water bound macadam (with or without a pitch carpet), etc., etc., adjoining the concrete road, all as may be necessary and desirable under the local conditions. The actual determination must be left to competent parties who will give due consideration to the local conditions and the principles referred to above.

This Committee therefore endorses with its approval and recommends the adoption by this body of a clause similar to that in the recent Report of the Special Committee (on Bituminous Materials for Road Construction, etc.) of The American Society of Civil Engineers, and as follows:

"Where Cement-Concrete Pavements are laid the edges should be protected and a sudden transition, from the pavement to any softer shoulder material, avoided by means of cement-concrete or other edgings or such reinforcement of the shoulder material as may be necessary."

Mr. Mullen: [illegible] built a great deal of 8-foot road and are still b[illegible] quite satisfactory. There is no appreciable wear on [illegible] ge. We build what might be called a concrete track in a mac[illegible] take care of the wear. In some places it is difficult to get crushed rock to build macadam shoulders for our concrete roads and this necessitates the use of gravel shoulders. With the narrow concrete and gravel shoulders there is some danger to traffic. Automobile drivers on the concrete will speed up and sometimes in turning out hit the gravel in such a way as to result in accidents. We have had that condition to contend with and to meet the condition the shoulders of the road must be very compact.

It is suggested that it might be advisable instead of having a gravel shoulder on each side of the narrow concrete track, to make a 2-track road; that is, in cases where only narrow concrete is to be built. With a 2-track road the concrete would be placed on the right-hand side going to town so that it would bear the heaviest of the traffic and the gravel would be placed on the other side. Often in good weather teamsters prefer to use gravel or macadam road. This is a point that I think is worthy of consideration.

Mr. Tunnicliff:—I wish to ask if there is anyone here who has had any experience with a concrete country road built with carpets along the edges.

Mr. Larned:—I think the recommendation for the adoption of the suggestion of the American Society of Civil Engineers is an important one, and that is, in the case of shoulders with a bituminous binder or carpet, it would serve to facilitate drainage and prevent absorption of water into the shoulder immediately adjacent to the slab, thus serving to prevent injuries to the slab at a later time. If the shoulder is sealed in that way by an oil blanket or by some penetration method, it will certainly serve to shed water more rapidly. I think that when we consider traffic conditions we seldom take into account that the improved road brings about conditions that we have never experienced before over that particular road. When we observe the number and character of vehicles passing over the road, we are often led to wrong conclusions, when we consider what the road will have to do when it does become improved. The improvement changes the character of traffic immediately. High speed is a pretty hard thing to prevent, and for safety alone, I believe that the road should be wide enough to admit the passing of vehicles at moderate speed without the necessity of going off on the shoulders. This certainly would protect the shoulders, reduce the cost of maintenance and be much safer.

Mr. Morse:—It has been stated that 8-foot pavements are giving satisfaction in Minnesota. One gentleman declares that it would be well to increase this width to permit the passage of two vehicles. When we increase the width we get into a more expensive proposition. The 8-foot pavement in Minnesota is built 6 inches in thickness and it does not crack. When we increase the width of that road to 16 feet, we must either increase the thickness or I fear there will be danger of longitudinal cracks. While I believe in a wide pavement I see this difficulty.

Mr. Mullen:—I wish to call your attention to that part of the report which states that, "In a 10-year period from the date of construction real

economy would have be ... th of the road crusts, so that nowhere would t' ... feet."

I believe a greater ... e we find that the traffic is greatly changed afte ... and where the funds will permit of it, a wider ... Minnesota, where we have built the narrow road ... of expense largely. But the narrow road has prov ... e exception of the possible condition I mention. I ... material is used in the narrow roads where the trav ... to such a narrow area the results are liable to be unsatisfa ... have excellent work to make a success of the narrow pave

REPORT OF COMMITTEE VIII

BITUMINOUS SURFACES FOR CONCRETE ROADS

Chairman—E. J. MEHREN
Editor Engineering Record, New York City

HENRY G. SHIRLEY
Chief Engineer, State Roads Commission
Baltimore, Md.

JAMES R. MARKER
State Highway Commissioner
Columbus, O.

The practice of covering a concrete road with a bituminous surface is of such recent origin, and the methods and materials used have been given so little scientific study that it is not possible at the present time to draw conclusions as to its value. The differences of opinion fall into two chief classes:

1. As to the advisability of preventing a concrete road from fulfilling its primary function—that of directly carrying traffic, and

2. As to the materials and methods which the present inadequate experience indicates are the best.

Fundamentally, it would appear that the surfacing of a concrete road implies a lack of confidence in the ability of concrete to withstand traffic. Many hold that the concrete of itself should bear the brunt and that the use of a protective medium is a confession that concrete has failed to justify the hopes held out for it.

On the other hand, are those who contend that a concrete pavement, no matter how well laid, will sooner or later crack and pit in spots, and, since these cracks and pits will be patched with bituminous material, it is wise to prevent this entirely by laying a carpet on the concrete surface.

As to the materials and methods suitable for coverings there are equally wide differences of opinion. This is undoubtedly due to lack of sufficient experience. On one point, however, there is a well defined opinion that tar is more suitable for carpet coats than asphalt. On the other hand, there is some testimony that asphalt has given good results.

It would appear, therefore, that investigations of bituminous surfaces for concrete roads should be divided into two parts:

1. Should concrete roads themselves bear the brunt of the traffic, or should some bituminous material be interposed to take the wear?

2. What has experience shown with reference to different materials and methods of application?

In conclusion, one point can be safely emphasized. It admits of no discussion. The concrete pavement itself, even if it is to be covered by a bituminous coat, should be laid with as much care as if it were not to be protected. This applies to the preparation of the sub-grade, and the proportioning, *mixing, laying* and curing of concrete.

DISCUSSION

Mr. Larned:—I beg to offer this suggestion in connection with the application of any bituminous covering for concrete. It has been found very difficult to secure a satisfactory bond between this layer and the concrete surface. I believe that this has been primarily caused by the presence of very fine particles of dust, which serve as a waterproof coat; and where the ordinary method of treating concrete will be by a street broom, followed perhaps by wire brooms, I believe you naturally add to the dust. I suggest that if some means could be found of applying an air-blast, by means of an ordinary pump carried on wheels, after the heavy dirt has been swept off, the surface can be more satisfactorily and thoroughly cleaned by air-blast than by any system of brooming. Furthermore, I believe that the concrete surface should be wet, prior to the application of any bituminous binder, and that the moisture should be allowed to disappear from the surface. I believe that any filler that is added will find a better bond if this practice is followed. Now water will clean the surface much better than brooming, and if you have ample water, as in city streets, I would clean the pavement with a hose.

I know of an instance in New Hampshire where an old Hassam pavement was in good condition but a little unsightly because of cracks. The pavement was thoroughly cleaned by a hose, and a half inch or less of bituminous coating was put on top with good results. The top is still in good condition today.

Mr. Tunnicliff:—I have had some experience with the application of bituminous tops, but my experience has been wholly with Dolarway. I find that the presence of particles of dirt, or any foreign matter, on the pavement makes an insecure bond. My experience shows also that moisture in the concrete makes an imperfect bond, just as dirt does. I have tried this out with concrete that has been laid at various times. At the time that we would apply the top coat we would start with concrete that had been laid for 4 weeks and we would cover a stretch of concreting and get up to where the concrete had been laid for probably 10 days. It was my experience that the concrete that was down the shortest length of time was the place where the top coat scaled off more quickly. I cannot account for that in any way, except because of additional moisture in the concrete.

Mr. Boorman:—There is now a system of assisting the binders. A very light oil is applied and evaporated, then upon application some heavier oil will take hold perfectly.

Mr. Gillette:—I think Mr. Larned is right in his contention that wetting concrete will cause asphaltic oil to sink into it, and bind better. I think the previous speaker is right if we are going to put filling on it, but it will help it if you are going to put on asphaltic oil.

Mr. Larned:—The question of applying a bituminous binder to the concrete that is 6 or 8, or even 10 days, old is a very different proposition from applying a binder when the concrete is 8 or 10 years old. The piece of road I am speaking of is 8 or 10 years old and has acquired its set and is not in process of shrinkage, as would be the case in new concrete. The shrinkage in new concrete will very naturally cause the separation between the binder and the concrete. I do not mean to suggest that enough water be left in the concrete to cause this trouble; I mean that the purpose of the application of *water is to* thoroughly clean the surface and then to disappear. In effect the

oncrete looks absolutely dry when the water has disappeared. That is the rime essential in the whole proposition.

Mr. Hewitt:—I have found in applying tar to a concrete road surface hat the road had to be perfectly dry. I found also in cases where the conractor had insisted on using an abundance of water in making his concrete hat it seemed to bring out what we ordinarily call laitance, to the surface f the pavement, which made a film on the top of the pavement and which re had to remove before the tar would stick to the pavement. I wish to sk, if any member of this Association has tried to apply two coats, first pplying one coat very hot, then afterwards one not so hot, and then putting he gravel on top.

Mr. Mehren:—Some specimens of stripped carpets were shown to the ommittee. On the bottom of these strips was a layer apparently of set oncrete, ranging in thickness from 1/16 to ⅛ of an inch. We made nquiry regarding the construction of the piece of road from which this trip of peeled material had come. It was tarred, by the way, and we rere informed that the section was laid under the most rigid inspection, and hat it had been carefully broomed before the bituminous material was applied; nd further, that the inspector had particularly been directed to see that here was no dust on the surface. The only conclusion we could reach was hat the concrete had been laid or mixed with an excess of water, and that his coat on the bottom of the peeled tar was laitance.

REPORT OF COMMITTEE IX

FINISHING AND CURING CONCRETE ROAD SURFACES

Chairman—F. E. Turneaure
Dean, College of Engineering
University of Wisconsin
Madison, Wisconsin

H. J. Kuelling
President, Wisconsin Highway Commissioners' Association
Milwaukee, Wisconsin

E. D. Boyer
Engineer, The Atlas Portland Cement Co., New York City

No attempt has been made to formulate specific recommendations or specifications, but we have endeavored to analyze the subject and present the salient features in a manner which may form a basis of discussion and future consideration.

In finishing and curing a concrete pavement the operations may be considered in three parts:

1. The securing of a surface which shall, in general, have the desired grade and cross-section.

2. Finishing the surface so as to secure the desired degree of smoothness.

3. Curing of the concrete so as to produce as hard and dense a material as is reasonably practicable.

SECURING THE CORRECT GRADE AND CROSS-SECTION

The question of accurate grade and cross-section is of considerable importance in producing a surface which will be free from undesirable irregularities. Small irregularities give unsatisfactory conditions for traffic at high speed, such as automobile traffic, while large irregularities give rise to depressions and pockets likely to hold water and become icy and also lead to unequal wear. To secure good results, grade stakes should be accurately set, and where side strips serve as grade lines, they should be set with care and be straight and true. The tendency of modern practice in the construction of hard road surfaces is to reduce the crown of the road to a minimim. If the results are to be satisfactory under these conditions, increased accuracy in grade and cross-section will be necessary.

Narrow roadways are usually brought to grade and line by striking off the fresh concrete by means of a board, cut to conform to the desired shape of the road, and resting at its ends on longitudinal strips laid to grade. Where care is used in setting these strips and manipulating the board, accurate results are secured. In the case of wide roadways and city streets grade points must be established at frequent intervals in order to secure the desired accuracy. There is much poor work along this line to be seen on many of our city streets, even where asphalt surface is employed. Much more care should be used *on this part of* the work than is the practice at many places.

FINISHING OF SURFACE

The method of finishing the surface of the concrete after it is brought to line and grade is a matter of considerable importance, although the wear of traffic will soon eliminate small differences in the degree of smoothness secured. One of the principal objects to be attained in the surface finishing, after the concrete is struck off, is to secure a surface layer which will be as uniform in character as practicable, and free from voids and other irregularities. The securing of a good dense and even surface is dependent, to a considerable extent, on the care with which the concrete has been shoveled and stirred into place. Uniform and careful workmanship in this part of the process is important. Concrete which has an excess of large stones at one point and an excess of mortar at another point will not wear uniformly, and cannot be made uniform in the finishing process.

A common practice is to finish the surface by means of a wooden float manipulated from a bridge. Good results can be, and have been, obtained also by the use of the shovel alone. To secure a surface which is uniformly somewhat rough, the use of a coarse broom is common and is to be commended, although a short period of wear will eliminate any differences due to brooming.

To secure additional roughness, especially on grades, grooves have often been made in the concrete. Results of such grooving have been variously reported, some reports being satisfactory while others show unsatisfactory results due to the rapid wearing of the concrete and the disappearance of the grooves. It is evident that to accomplish any very lasting result the grooves must be fairly deep and not spaced too closely. A diagonal rather than a transverse system appears to be an advantage, but is not so easy to construct. Longitudinal grooves are of very doubtful value.

Where the experience with grooves has been satisfactory, it appears that the surface layer of concrete has been of rather superior quality and made of fine aggregate. This would appear to be a reasonable condition, and from observation of some of the members of the committee, as well as from various reports, a grooved surface made in rich, high-grade material will show a very satisfactory durability. Grooves would hardly appear to be advisable in connection with a coarse aggregate.

CURING

The curing of the exposed surface of the concrete is one of the most important parts in the entire process. Good concrete can easily be spoiled by a too rapid drying out, and under the conditions frequently met with, such a result may easily follow, unless great care is taken to protect it. Laboratory tests of concrete cured under different conditions show that it is easy to increase the strength 50 per cent by a proper treatment over what may be secured under improper conditions. It appears, also, that the effect of rapid drying is even greater on the hardness of a concrete surface and on its permeability than on its crushing strength. Concrete allowed to harden without proper curing shows a soft surface which can readily be scratched. It is, at the same time, much more porous than properly cured material and will show greater deterioration from frost action. The length of time during which concrete will continue to absorb water in chemical combination is much greater than is generally supposed. While the hardening process continues quite slowly after the lapse of a month, it is also true that with a continued supply of water, increase in strength beyond that time will be very consid-

erable. The critical time in securing a good instead of a bad result is included, perhaps, in the first week; but for best practical results a week is often too short.

The essential thing is, of course, to keep the concrete wet a sufficient length of time to secure the best results consistent with the expense involved and the improvement which will result. In hot summer weather it may be considered as absolutely necessary that this process shall be continued for at least 7 days. A number of specifications require 14 days, and a longer time is occasionally demanded. A mere sprinkling once a day in hot, sunny weather is certain to be very ineffective. When it is remembered that the actual evaporation from a free water surface during hot, dry weather is as great as ¼ inch per day, it is obvious that a single daily sprinkling, with no protection against evaporation, is very inadequate. To prevent evaporation, an excellent and common practice is to cover the surface as soon as practicable with a layer of earth. This serves to reduce the evaporation very greatly and would seem to be almost necessary under high summer temperatures. The concrete thus covered should be sprinkled frequently enough to keep the surface in a moist condition. For the first 24 hours after laying, or until the surface can be safely covered with earth, a canvas covering on hot windy days is advantageous and is used by some engineers. Traffic should be kept off at least 3 weeks and longer when possible, especially late in the season when the temperatures are relatively low.

As a matter of some value, your committee has made a search through recent engineering literature on the subject assigned to it. The results of this search may be briefly summarized as follows:

Out of twenty-one reports of actual construction and seven specifications and papers on this subject, the method of finishing was reported as follows: Fifteen finished by means of a float, four by means of troweling. Thirteen broomed the surface.

In the matter of curing, three reported as using canvas, eight as using sand and earth; four reported 7 days as the period of sprinkling, two 14 days, and one 21 days.

DISCUSSION

Mr. K. H. Talbot:—In connection with the brooming of the surfaces and the drying out I would like to tell of an investigation of a road that was reported as being chalky. I found that it had been broomed and was apparently chalky on the top within two or three days after the brooming. I could take a knife and scrape off the ridges that were left by the brooming, and find the hardened concrete beneath. I ascribed this to two things: the ridges offered more area for the wind to strike and resulted in drying out, and the film of concrete in each one of the ridges was small, so that the drying out was very rapid. I feel, therefore, that under summer conditions, with insufficient curing and protection, it is a mistake to broom the surface.

Mr. Larned:—There is another injury that can be caused by brooming. The ordinary stable broom is made of rattan bristles that are stiff. These bristles are set practically at right angles to the handle, so that when the broom is dragged through the concrete it not only creates a ridge, but it disturbs a very considerable portion of the concrete itself. Besides, that application is not made to the surface until the concrete has taken a consider-

ble set. I would very strongly advocate the use of the wood float only. The advantage produced by brooming is only temporary and the ridges soon wear off. The brooming certainly destroys some of the slab.

Mr. Gillette:—In addition to the three ways of curing or wetting the urface of concrete mentioned by the committee, I should like to call your ttention to a fourth method that has been introduced in California. It is laimed to be very effective and quite as cheap as the other ways. This is o build up small dikes across the concrete and to flood the space with water o a depth of about two inches. The trouble of having to scrape off the lirt afterwards is eliminated.

Mr. Rupert Smith:—Curing by steam is another method that has been nentioned. This offers considerable possibilities, especially under winter onditions.

Mr. Myers:—With the temperature not over 80 degrees, would any urface covering be necessary, or would sprinkling be sufficient?

Mr. K. H. Talbot:—In my opinion the covering is necessary even when he temperature is as low as 80 degrees. The water will never be at that emperature, and, therefore, sprinkling directly on the concrete has the effect f cold water coming in contact with a warm surface, as the concrete will ssuredly be at the same temperature as the air.

Dean Turneaure:—The suggestion of curing by ponding, as is done in California, and the method of curing by steam, are certainly good. It would eem that the curing proposition is really the important point in the report f this Committee.

REPORT OF COMMITTEE X

ECONOMIC METHODS OF HANDLING AND HAULING MATERIALS FOR CONCRETE ROADS

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Donald D. Price
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Philadelphia, Pa.

The materials to be handled in the construction of a concrete road are:

(1) Water,
(2) Cement,
(3) Sand, and
(4) Gravel or Stone.

Water: The first mentioned material, water, is quite apt to be given scant consideration by the road builder whose experience has been limited to work within cities or villages. Likewise the engineer or contractor who has never before attempted road construction is prone to underestimate the cost of securing and delivering water, whether for concrete or macadam roads in country districts. In arid regions a mistake of this sort may readily result in serious financial loss.

The chairman of your committee has been financially interested in the building of concrete roads under conditions that have served to emphasize the importance of considering the cost of water and of ways and means to reduce that cost.

Water, it should be remembered, is used for at least three purposes in building concrete roads: (1) to wet the subgrade; (2) to mix the concrete; and (3) to keep the concrete moist for several days after it is laid. On a sandy subgrade that must be wet and rolled before laying the concrete, as much as 100 gallons of water per cubic yard of concrete may be used merely to wet the subgrade. Then an additional 50 gallons or more per cubic yard will be required to mix the concrete wet enough to flow readily. Finally as much as 80 gallons per cubic yard of concrete will be needed to keep the concrete wet for a week after it is laid, if the air is very dry and if there is much wind. A total of 230 gallons of water, weighing 1,900 pounds, has been required for each cubic yard of concrete, in one case known to your chairman. More than that would have been used had the concrete not been kept covered with a layer of earth an inch or more thick. The earth, of course, retarded evaporation of the water. The water in this case was hauled in tank wagons, so there was no guessing as to the total amount used, although its distribution among its three different uses was not accurately determined.

A ton of water per cubic yard of concrete may probably be regarded as the maximum that need ever be required. A quarter of a ton of water per cubic yard is probably the minimum, if there is to be any sprinkling of the subgrade and of the concrete. A 2-mile haul at 25 cents per ton-mile results in a cost of 50 cents per cubic yard of concrete for hauling the water where the maximum amount is needed. This is astonishing indeed to the contractor who has been accustomed to mix and place concrete for 50 cents a cubic yard under certain conditions.

When large quantities of water are to be moved considerable distances, pipe lines should usually be laid along the road and the water should be pumped. Quite a common mistake, when this is done, is to use pipe of such small diameter that the friction head makes it impossible to deliver the quantity of water needed. Thus a 1-inch pipe is often laid where a 2-inch pipe is needed. Any engineer, however, is competent to estimate the size of pipe required under given conditions. It should be remembered that the head against which the pump is acting is the sum of the static head and the friction head, and that the cylinder of a pump may be cracked under an excessive pressure thus developed.

Within the confines of a report of this character it is impracticable to discuss at further length the problem of water supply for concrete road work.

Cement: In the handling of cement there are two very common economic errors in evidence: (1) failure to provide a large stock of cement; and (2) an attempt to locate the cement nearer the concrete mixer than is necessary. The concrete road builder is so often forced to wait for the delivery of cement by rail that he eventually learns that it pays to tie up more capital in a stock of cement than to foot the bills incident to delays in securing it by rail. Although cement dealers are usually prompt in making shipments, the railways are not always to be relied upon. For this reason, cement should be accumulated in stock-houses or stock-tents. Tents, with wooden floors made in sections, can be placed at short intervals along the road. From them the cement can be delivered in small gasoline motor cars of the kind that cost about $500 each. Such a car will carry 10 or 12 bags of cement and can be run into the tent to be loaded by the driver of the car. The car will travel from 15 to 20 miles an hour loaded and 18 to 25 miles an hour empty, at a total cost of about 4 cents per car-mile one way or 8 cents per car-mile of effective hauling work. The resulting cost of hauling cement short distances can not be equaled in any other way known to your committee.

Sand: After the subgrade has been sprinkled and compacted by rolling, it is customary to dump sand and gravel on it in piles. Then these materials are loaded into barrows and wheeled to the concrete mixer which travels along the subgrade, leaving the layer of green concrete behind. This, we think, is at present the most common way of placing concrete. But it is not the only way, and there are some contractors who maintain that it is not the cheapest way. Another method is to place both the mixer and the stock piles on one side of the road. The materials are then usually shoveled directly into the mixer, or into a bucket or skip, that delivers into the mixer. In the west it is not unusual to see Fresno scrapers used to drag the sand and gravel from the stock piles to the mixer. In some cases the scrapers deliver the materials upon a platform whence they are fed by gravity into a skip that delivers into the mixer. In these cases the mixer is not moved until about 600 to 1,000 feet of road have been built in both directions

from the mixer, the concrete being hauled in one-horse concrete carts or in one-man concrete buggies.

The differences in cost between these two methods seem ordinarily not to be very great; but there may be conditions that justify a choice of one method in one place and of another method in another place. Thus, if laborers are scarce and mules or horses plenty, the latter method may be preferable.

As above stated, a small $500 motor car can be economically used to haul cement short distances. To do this, the body of a pleasure car is removed and a platform placed on the rear part of the chassis. This method of hauling cement was first devised by one of your committee, it is believed; and he now suggests that the same method might be advantageously applied in hauling concrete from a mixer to the road. To do this, a concrete bucket would be mounted on the chassis and the concrete would be discharged from the bucket through a trough. It might be desirable, in using such a method, to provide a pair of trussed planks that would span the road and be used as a runway for the automobile.

So much has been written about the unloading of cars of sand, etc., with drag scrapers, clam shell buckets, and the like, that we shall not here go into these labor saving methods. An ingenious modification of old methods was recently described. It consists in dumping sand or gravel from a hopper-bottom car into a pit dug beneath the track. The materials are thence dragged with a power-scraper up an incline and dumped into a bin. This method has much to commend it where hopper-bottom cars are available.

Gravel and Stone: Although cement and even sand may be rehandled without adding greatly to the cost of a concrete road, an attempt should always be made to avoid rehandling the gravel or broken stone. Broken stone is particularly hard to shovel up when dumped on the ground; and besides, it constitutes a very large part of all the materials to be handled. Stock piles of sand may often be needed to avoid delays in freight shipments; and in such cases, they may be placed at relatively short intervals along the side of the road. If broken stone or gravel is also received by rail, it is generally wise to build the stock pile at the place where the cars are unloaded. Then a clam shell bucket can be used both to unload the cars into the pile and to load the wagons from the pile.

If large stock piles of stone or sand are to be made along the road, care should be taken to scrape a smooth place upon which to build the pile. With a road machine and a roller, a place can be so graded and compacted that very little of the material in the stock pile will be lost. Care should be taken to locate such stock piles where heavy rains will not wash the materials away.

In the handling of broken stone from portable rock crushers, two economic errors are common: (1) bins are too small; and (2) their bottoms are not steep enough. Small bins make it necessary to stop the crusher if there is not perfect coordination in hauling and using the materials. Bottoms that are flatter than 1 to 1 prevent the stone from running rapidly, and thus delay the loading. This last is important enough with team-hauling, but it is much more important where motor trucks or traction engines are used.

Hauling by Power: Although the horse and the mule will long continue to be used on road work, their "day" for hauling road materials is fast passing. We have already given some details relative to the use of small motor cars *for hauling* cement short distances. Motor trucks of 3-ton to 5-ton capacity

are becoming popular for hauling wherever the roads are sufficiently good to admit their use. Recently the use of "trailers" has added much to the popularity of motor trucks. While a "trailer" decreases the speed of transportation it greatly increases the tonnage hauled each trip.

Traction engines hauling trains of wagons have been in successful use for so many years that we need say little about them.

As to the relative economic merits of motor trucks and traction engines, no data yet available point either to the one or the other as being clearly preferable. In making comparisons, several things other than the ton-mile costs while hauling during the road building season should be kept in mind: (1) whether the hauling plant can be used for other purposes than road building; (2) whether it can be used in the winter; (3) whether it destroys existing roads and subgrades sufficiently to be objectionable; (4) whether there is room to maneuver—turn around, etc.

Not a few men are making it their sole business to contract for hauling. Such men often work their hauling plant two shifts daily, running about 18 hours out of the 24. This greatly reduces the interest cost per ton-mile. A not uncommon price is 15 cents per ton-mile over rough roads and under severe conditions.

Conclusion: Your committee has made no attempt to discuss concrete mixing and placing, for there are fully a dozen books in which this matter is given much space. Nor has it seemed wise to repeat much that also exists in book form on the general subject of shoveling and hauling. A few suggestions as to the recent developments in concrete road work have been indicated in the hope that other road builders will add their quota.

DISCUSSION

Mr. Gillette:—The common methods of hauling are well known to all, so that the report in this regard is purposely brief. There are two methods, however, which have not been so well written up and so long used in this country. One is hauling with motor trucks and the other is hauling on tracks. The latter idea will be discussed by one more conversant with that method.

The hauling of materials for concrete roads differs essentially from that for macadam or gravel roads only in one particular, and that is that there is a vast amount of water to be hauled or piped in the building of concrete roads.

In addition to hauling by motor trucks, another California method of handling gravel and sand is by the use of a Fresno scraper. This is a modified drag scraper about 5 feet long, 16 or 18 inches high, and 16 or 18 inches in depth. Four mules abreast, driven by one driver, will handle this scraper. For short distances, say, 100 feet, the Fresno will haul fully ½ cubic yard. In going long distances it will lose ¼ of its load, particularly in going down hill. In making a cut from a bank and loading it into wagons, a platform with a hole in it is erected and the material dragged into that drop and dumped into the wagon. In this way material can be loaded for approximately 5 cents per cubic yard. In one gravel pit a contractor was turning out something like 125 cubic yards of gravel with just one Fresno team handling all the material. In this section of the country we who have been accustomed to use 6 or 8, or even 9, wheelbarrow men to run the gravel or broken stone to the crusher or screen would be surprised to see only 1 man in the gravel pit, 1 man running the elevator, or machinery which drives the crusher, and 1 teamster handling 4 mules with the

Fresno scraper. It seems to me that it would be well for those of you who are going to the Panama Exposition to spend a little time inspecting construction work in California, where a vast number of tricks have been developed because of the scarcity of labor and its consequent high price.

Mr. Hellmann:—Teams are scarce at times, and generally at the particular time when they are most needed, being therefore not absolutely reliable. You have known of work that has been badly crippled on account of teamsters' strikes, which is another example of their unreliability. Their capacity in hot weather, as well as on muddy roads, is vastly cut down. They are slow, covering a distance of not over 20 to 25 miles per day.

While an advancement over teams, traction outfits share their shortcomings as far as speed is concerned, and they, too, are more or less dependent upon good weather conditions. It is hardly possible to operate a traction outfit in rainy weather on muddy roads, without eventually damaging the road to some extent. Further, on account of their excessive weight, they cannot travel over many of the country bridges encountered in road-building.

Motor haulage can really only be considered, as we have heard from Mr. Gillette, where the roads are sufficiently good to permit their use.

A system, therefore, that does away with these shortcomings and offers a number of advantages which I will define later, certainly deserves some consideration where efficient and economical hauling is desired.

The system I have reference to is the hauling by means of an industrial railway equipment consisting of portable tracks, double side steel dump cars and locomotives, all of 2-foot gauge. This system, on a broader scale, comprising larger capacity cars, mostly 3-foot gauge, is used extensively as you know, in railroad construction work for the hauling of excavated material for cuts, fills, etc. Few people realize when suggesting this means of transportation on road-building jobs, how easily a special outfit of this kind is installed, and how cheaply it operates.

Consider, therefore, that the track on which the cars and locomotive operate is an already built up unit, including steel ties to which the rails are fastened, and including angle joints, all ready to be laid down. Two men are able to handle a section, which comes in standard 15-foot lengths, and weighs 225 pounds per section for 16-pound rail, and 270 pounds per section for 20-pound rail, with preference for the latter being the rule. You can figure that the laying of the track, consisting in connecting of the different sections, will not exceed ½ cent per foot of track, or about $26 per mile, where it is laid from the point of arrival of the material.

Where the track is to be hauled across the country for a distance, or where, after being used on one job, it has to be transferred to another one, 3 or 4 miles away, you can reckon on 1 cent per foot, or about $53 per mile as the average cost for such hauling, and the laying and connecting at the new location.

The above figures for laying, hauling and connecting of the track are figures, as I might particularly mention, at which this work has been sublet many a time, and represent no guesswork, but true, actual cost.

Switches likewise are one unit of the same length as a section of track, so that where turnouts are to be made any straight section can easily be replaced by a switch or curve of the same length.

The cars used in connection with this track are of the double side steel type, 1½-yard capacity, weighing about 1,000 pounds each. I would like to draw your special attention to the dumping features of this particular type of V-shaped car. There is no danger of the contents of the car when

dumped, rolling or falling back onto the track and interfering with the operation of the train. The car clears itself entirely, the center of the dumped load being about 3 feet from the edge of the rail.

An advantage also worth mentioning is that there is no guesswork about the contents of each load as there is in the case of wagons, because you can be sure that each car always holds the same amount of material.

These cars are used not only for hauling sand, gravel or crushed stone, according to the specifications of the road, but are also used for handling the cement, one car generally carrying about 10 barrels.

I have also heard of instances where water was carried along in the train in a car easily designed for this purpose.

For hauls shorter than ½ mile, a team of horses hauling 7 loaded cars will be economical, whereas on hauls exceeding this distance, the preference will have to be given to locomotive haulage.

The locomotives most widely used are a 20-horsepower or a 30-horsepower engine, weighing 13,000 and 15,000 pounds respectively.

As astounding as it may sound, I have witnessed the 30-horsepower engine pull 26 loaded, 1½-yard cars up a 5 per cent grade, not as a record performance, but as an hourly duty for weeks. This seemed to me to be so remarkable that I checked up the grade and then secured a profile from the County engineer, which verified the above figure.

For steeper grades, say 6 per cent to 10 per cent, a geared engine is used to good advantage. While somewhat slower and considerably heavier (just about double the weight) it still can operate with perfect safety on a 20-pound track, the weight being distributed over 8 wheels instead of 4.

This system as a whole has been found to have the advantage of working under almost any weather conditions, thus enabling the piling up of the material alongside of the road even in times when the weather does not permit of actual work. It will work with an average speed of between 8 and 12 miles per hour, therefore covering much larger mileage per day than what would otherwise be possible, and at a cost that will be materially below the cost of hauling by other means as later figures will indicate. This system has therefore strong advantages in the points where the others are weak—independence from weather conditions, and speed. Let me add to these the fact that the track can be laid over any improved road without the least fear of damaging same, or making any resurfacing necessary. The outfit also requires less space for maneuvering than is required by a team or traction outfit, as the overall length of the ties is only 32 inches, so that this is all the space required.

There is a Milwaukee County concrete road where the material came in from both sides of the road to be built, necessitating, therefore, the hauling of the material on the berm, because it was, of course, impossible to haul over the green concrete. The space available was too small for either a team or traction outfit, or motor truck, and this track, car and locomotive system was really the only solution in this case.

You, of course, realize that the locomotive does not need to be turned around, as it pushes the cars just as well as it pulls them, and both the 20-horsepower and the 30-horsepower engines are able to go through one of the 15-foot switches, which have a radius of 30 feet.

Besides being used for the hauling of road building material, this same plant can be used for any earth moving proposition. Where there are cuts or fills to be made, the cars can be put to work under a steam shovel just as

easy as being used for hand shoveling, with the advantage that for the latter the total height of the car is considerably less than the height of a wagon.

The cars can be held in a semi-dumped position, and in this position filled to ¾ of the capacity, the height in semi-dumped position being 30 inches, and the total height 46 inches.

Needless to say, the plant can be used in the winter as well as in summer.

As to actual cost data on hauling with this outfit, you realize it is always a risky undertaking to lay down set figures, because the figures will, of course, vary according to local conditions and the skill of the contractor. I am, however, in position to give you a few figures compiled from actual work done last year in Sargent and Embarrass Townships under the supervision of the Illinois State Highway Commission. In this case the townships rented a complete outfit consisting of over 6 miles of track, some cars and locomotives; and the state guaranteed to the commissioners that the cost of hauling on the longest haul, which, as stated, was over 6 miles, would not exceed 63½ cents per cubic yard for the entire distance, or slightly over 10 cents per cubic yard mile. Your attention is drawn to the fact that this figure is the cost per cubic yard mile, and not per ton mile, the cost per ton mile, of course, being proportionately less. Upon completion of the job it was found that the actual cost did not exceed 54 cents, or 9 cents per yard mile.

The above figures were, as stated, on the basis of renting the outfit, and include besides the rent, the freight to and from destination, the cost of laying the track, the cost of operating the equipment, the proportionate expenses of a superintendent; in fact everything that can be charged up under the item "hauling costs." Had the outfit been owned instead of rented, these figures would without doubt be more favorable, because the depreciation figured against one year's work as a rule will not exceed 15 to 20 per cent of its cost, whereas the rental figures are of necessity higher than such depreciation. Besides, in case of ownership, the item of return freight need not be considered.

As a basis, I might say that contractors are accustomed to figure on team haulage 25 cents per yard on the first mile, and 20 cents per yard on each additional mile. To give a comparison of this cost if done by track, cars and locomotives, a figure of 8 to 9 cents per yard mile is amply safe. I have letters from contractors using this outfit, stating that their cost for hauling after the track is laid, has been 10 cents per cubic yard for a distance of five miles, or 2 cents per cubic yard mile. This figure of 2 cents has to be understood of course only for the operating of the outfit and the dumping of the material. If another 2 cents is added for the laying of the track, and another 4 cents as a maximum for depreciation, the figure of 8 cents to 9 cents per yard mile, as arrived at on the Illinois job, is verified.

While the cheaper hauling is a great attraction, I consider the possibilities of building more roads in one season and being very much more independent of labor and weather conditions, items of at least as much importance in favor of this system.

Mr. Morse:—There are one or two things to which I would like to call the attention of the Conference. Mr. Gillette spoke of placing the stone upon the subgrade, or on the soil outside of the roadway, and stated that this ground should first be compacted. I find that it is customary to shovel it directly from such a position into the barrows, or into the mixer scoop. I think there are some objections to this method of handling stone. In the first place, when the material is reshoveled certain particles of soil get into the scoop and

thence into the concrete. These, being lighter than the stone, will rise to the surface causing pinholes, which we have all seen and which we have heard mentioned by the maintenance committee.

I have been specifying that from 1 to 2 inches of sand be dumped upon the foundation first, and then the stone placed on top of this. I found this very practical and not altogether unsatisfactory to the contractor. The sand is shoveled up again with the stone, and suffices to increase the cementing of the small particles of the concrete. This usually increases the efficiency and value of the concrete, for there is generally too little of the small material used in concrete pavements. Another important feature is that the sand makes the shoveling of the stone easier, which is in line with the economic study of this committee.

In some cases that I have observed, the stone is shoveled directly into the mixing scoop. The amount of space available limits the number of men to 5. The capacity of a man in an ordinary day is from 15 to 20 yards of stone. The capacity of the usual street paver is about 200 cubic yards per day. Consequently, this method does not consume the capacity of the mixer. A comparative cost of shoveling directly into the scoop, using 5 men, or shoveling into wheelbarrows and then dumping into the scoop, using 10 men, was made. It requires 22 men at $2.50 a day to properly run a mixer using 5 men shoveling. This means $55 a day for labor expended, resulting in about 450 square yards of concrete, or 12¼ cents per square yard for the labor. With 10 men shoveling directly into the hopper and 22 men on the mixer, the cost will be $67.50. This method will produce about 800 square yards at an average labor cost of 8¼ cents per square yard. This economy results in the saving of 4 cents per square yard, which, though small, is important enough to take into consideration with the other economies advocated.

Mr. Hellmann:—In the track system some contractors load the material into an elevated bin holding about 40 tons, or the contents of a railroad car, instead of loading each individual car. The loading outfit is then able to work whether or not there are cars ready to be loaded.

When emptying the cars, the train is generally in motion so as to distribute the loads more evenly over the road and to save some raking.

No difficulty is encountered in crossing the standard gauge tracks. A short section track is used and the wheels simply ride over the standard gauge track. After a train has passed, the short sections must, of course, be removed. Some railroads will not permit such a crossing unless a flagman is stationed at that spot. Such flagmen can generally be obtained for about $6 per week.

The track can be laid on the berm or nearer the center of the road. In some cases, where the berm is only 2 feet wide, it would be impossible to haul with wagons or traction outfits because of insufficient room. With the old method it often takes 4 horses to pull a 2-yard load on a dusty, sandy road, whereas with the track, 1 horse can pull 5 cars averaging about 7½ yards, or 2 horses can pull 7 yards and a steam shovel.

On grades exceeding 6 per cent geared engines can be used to advantage. Such an engine would go up a grade of 10 per cent and pull 15 cars, or a load of 15 yards.

Mr. Spackman:—I would like to call your attention to an inconsistency that has struck me in all concrete road construction. The committee on aggregates speaks of washed gravel and the limiting of fines that will pass a 50-mesh sieve to 10 per cent; yet I have never seen a concrete road built in which the *aggregate, both fine* and coarse, was not dumped on the ground

and shoveled up. The contractor shovels clean, because he does not want to waste the sand and stone, and the foreign material that you are likely to get into the concrete is, I think, responsible for much poor work. I think Mr. Gillette's suggestion of compelling the stock space to be rolled to avoid such a possibility is a very important one.

Mr. Melloy:—I believe the most important factor of this question would be to provide sufficient funds to put a competent man on the construction to supervise it. The contractor builds roads to make money and is expected, therefore, to practice every economy for himself. The majority of the states provide the small sum of $2 or $2.50 per day for some man who is not able to do anything else, or who knows little, to supervise the construction of as important a thing as a concrete pavement. I would suggest that it would be good economy to employ a good inspector at $5 per day, and thus to get some man who knows something about the construction.

Mr. Larned:—I would like to suggest the use of boiler plate sections deposited along the roadway on which to place material. These would greatly increase the shoveling capacity of a man, and at the same time avoid the objection of picking up dirt.

Mr. Gillette:—I agree that it is highly important that the inspector be a competent man. To get such a man we all know that we must pay a price in excess of that ordinarily paid to inspectors. I believe that no man should be an inspector who is not a graduate in road work from some engineering college; first, because I have yet to find such a graduate who is a dishonest inspector; and, second, it is good experience for a young man who hopes to be a resident or division engineer in road construction.

Apparently there has been a misconception regarding the statement of rolling the ground for stock piles. Stock piles can be placed either on the earth on the subgrade, or alongside the road. I, personally, prefer to see them placed alongside the road. I had that in mind when advising clean scraping and hard rolling for stock piles.

REPORT OF COMMITTEE XI

MIXING AND PLACING MATERIALS FOR CONCRETE ROADS

Chairman—PAUL D. SARGENT
Chief Engineer
State Highway Commission
Augusta, Maine

ARTHUR H. BLANCHARD
Professor of Highway Engineering, Columbia University, New York City

C. W. BOYNTON
Inspecting Engineer, Universal Portland Cement Co., Chicago

In the construction of concrete roads, probably no really important part of the work is given less consideration, in specifications and in the field, than the actual mixing and placing of the concrete.

The following notes, based upon observations in the field, and the results of tests, were prepared with a view of pointing out the difference between good and bad practice, and to serve as a basis for recommendations covering this phase of the work.

THE MIXER: The concrete mixer should be of the batch type provided with an automatic water tank, traction drive and power loader. Mixers having a boom and bottom dump bucket of sufficient size to convey one complete batch for placing the mixed concrete, are preferred. However, buckets of other types and sizes, open troughs and revolving tubes can be used, and will give good results.

An abuse of the revolving tube distributing method lies in operating batch-mixers so equipped as continuous mixers, the supposition being that as the tube is provided with blades and revolves, the materials are mixed in the tube. This tube serves only as a conveyor and cannot to any degree take the place of or serve as a mixer.

Concrete cannot be successfully conveyed or delivered through a trough or spout through which it must flow by gravity, for if it is mixed to a consistency such that it will flow at the required angle, the concrete will be too wet for the best results.

The mixer should be provided with a suitable automatic water tank which can be quickly filled and emptied, so that when once determined, the required amount of water can be added to each batch of concrete. A number of so-called automatic tanks on mixers are not satisfactory owing to their limited capacity, delay in filling and emptying, and to the fact that they depend, for successful operation, upon a constant water pressure. Water is pumped on most road jobs, with small gasoline or steam pumps, and it is not possible to maintain uniform pressure in the feed line.

An automatic measuring tank of the required capacity, that may be emptied quickly, connected by means of a comparatively large pipe, with an auxiliary or storage tank of about 50 gallons capacity, would be more satisfactory than the one tank system commonly used.

Where necessary to keep from cutting up the sub-grade and to facilitate moving, the wheels of the mixer should be run on suitable planking. Material of good quality, 3 inches thick by 10 inches wide, in comparatively short lengths, with square ends, will be found satisfactory for this purpose.

The power loader or skip should be of sufficient size to hold all the materials required for the batch. In charging the skip a part or all of the coarse aggregate should be placed first, and the cement, fine aggregate, and remaining coarse aggregate, if any, on top of this. All the cement should be in the skip before the last of the aggregate is added. If charged in this manner there will be less tendency for the materials to stick in the skip when emptying and less loss of cement on windy days. A systematic method of loading the skip will also serve as a check on the right amount of material being placed each time.

The filling of the skip is accomplished in practice in two ways—by the use of wheelbarrows and by shoveling direct from the supply piles into the skip. This latter practice, however, should be discouraged, for accuracy is impossible, and it encourages carelessness. Besides, the entire loading gang loses time waiting while the skip is raised and lowered.

MIXING CONCRETE: No important operation is given less attention than the mixing of the concrete. Frequently in practice, the time the materials remain in the drum is governed only by the speed of the gang charging the skip. At times the batch mixer is operated practically as a continuous mixer, by fastening the discharge scoop or spout so that there is a constant flow of concrete from the mixer.

The quality of concrete is largely dependent upon thorough mixing. To insure thorough mixing the R. P. M. (revolutions per minute) of the mixer and the time the complete batch, including water, remains in the mixer, should be specified. To specify either the R. P. M. or the time is not sufficient as is plainly shown by the following tabulation of field observations:

Job	Mixer	R. P. M.	Mixing Time
1	Smith	10	1½ min.
2	Koehring	18	40 to 45 sec.
3	....	18	30 sec.
4	Foote	14	45 sec.
5	Eclipse	13	2 min.
6	Austin Cube	16	50 to 55 sec.
7	Smith	11	2 min.
8	Chicago	24	30 sec.
9	Foote	18	25 sec.
10	Koehring	18	20 sec.
11	Austin Cube	16	20 to 60 sec.
12	Koehring	32	15 sec.
13	Austin Cube	16	10 sec.
14	Ransome	7	1 min.
15	Koehring	18	20 sec.

Upon inquiry of the manufacturers it was found that the R. P. M. of the drum of batch mixers varies for different makes and for different sizes of the same make, as shown by the following table compiled from data furnished by the manufacturers:

CAPACITY AND SPEED R. P. M. (REVOLUTIONS PER MINUTE) OF PAVING MIXERS

Name of Mixer	Rated Capacity cu. ft. unmixed material	Capacity Bags of cement in 1:2:3 Mix.	R. P. M. of Drum	Name of Manufacturing Company
Austin Cube	14	2	18	Municipal Engineering & Contracting Company.
	22	3	18	
Chicago Mixer	10	1	15	Chicago Concrete Machinery Co.
	14	2	12	
	23	3	11	
	30	5	10	
Smith Mixer	14	2	14	T. L. Smith Co.
	24	4	12	
	33	5	11	
Foote Mixer	7	1	18	Foote Concrete Machinery Co.
	13	2	16	
	23	3	14	
Koehring	7	1	20	Koehring Machine Co.
	12	2	17	
	20	3	16	
	24	4	15	
	30	5	15	
Oshkosh	18	3	18–20	Oshkosh Manufacturing Co.
Milwaukee	8	1	20	Milwaukee Concrete Mixer Co.
	14	2	18	
	20	3	18	
Ransome	8	1	21	Ransome Concrete Machinery Co.
	10	1	21	
	18	3	20	
	21	3	20	
	24	4	17	
	28	4	17	
Standard	7	1	16	Standard Scale & Supply Co.
	15	2	14	
	21	3	14	
	30	5	13	
Chain Belt	10	1	20	Chain Belt Co.
	15	2	18	

Because of the shape and arrangement of the interior of the drum, the rate at which a given mixer is operated has a direct bearing upon the quality of the concrete, therefore the drum should be operated at approximately the speed at which the manufacturer claims the best results would be obtained.

It is recommended that all specifications contain a clause to the effect that all the materials in any one batch—including the water—should remain in the drum of the mixer at least 45 seconds before any of the concrete is discharged.

In all cases the drum should be completely emptied before the next skip of materials is dumped into the mixer. This is a source of constant controversy between the engineer or inspector and the contractor, especially where the mixer used is equipped with an open trough, or with a boom and bucket when the bucket is not large enough to hold the whole mixed batch.

The operator should start the water into the drum as soon as the skip is in position to dump—that is, it is not necessary to mix materials dry before adding water.

CONSISTENCY: The practice on road work is to mix concrete entirely too wet. This causes a separation of the coarse materials from the mortar, resulting in stony pockets throughout the concrete. Where the concrete is mixed too wet, it is practically impossible to obtain and hold the required crown, and stony patches frequently appear on the surface after it has been finished, owing to the flow of water and mortar to the sides. In striking off and floating concrete mixed with an excess of water, it is also practically impossible to obtain a surface of the desired character, as the excess of water collects in and hides depressions and other inequalities in the surface, which cannot be corrected as they are not apparent until after the water has evaporated.

In addition to the difficulty encountered in getting wet concrete into the pavement in a manner which will give the best results, laboratory tests and results observed in the field show that, other things being equal, a wet mixture is of inferior strength and quality to concrete of a medium wet consistency. The marked effect in the strength of concrete that a variation in the consistency produces, is shown in the following table of results of tests made in the Sheffield Scientific School of Yale University by Chas. J. Robinson. See "Engineering News," Vol. 69, No. 21, May 22, 1913.

Per cent Water	7 Days†	30 Days*	60 Days†
20	2052	2777	3194
22½	2173	3132	3305
25	2277	3278	3388
27½	2500	3516	3597
30	1722	2874	3166
32½	1413	2416	2666
35	1222	1977	2388
37½	1097	1819	2173
42½	652	1500	1888

*Average of two tests. †One test only.

In this test water was added from 20 per cent to 42 per cent according to the following method:

"As a minimum, enough water was taken to moisten the stone and sand, and then there was added 20 per cent (of the amount of the cement by weight) water. Each subsequent mixture was increased by 2½ per cent water. It was noted that the 42½ per cent mixture was about as wet as is used in the average wet mixture, though drier than some slushy mixes."

As yet there is not sufficient data on which to base a definite conclusion relative to the influence of the consistency of concrete upon the expansion and contraction; however, information at hand seems to show that this action is influenced very largely by the consistency.

Owing to the methods employed in striking off and finishing the surface of concrete pavements, there is little likelihood of mixing the concrete too dry. Concrete mixed with an excess of water is easier to mix, to handle, to place and to finish, than concrete of the proper consistency, which explains the tendencies toward wet mixtures.

The amount of water in the concrete should be such as to cause it to settle to a flattened mass when dropped from the bucket, but not sufficient to cause it to flow readily on the sub-grade. The consistency should be such

as not to require tamping, but not so wet as to cause a separation of the mortar from the coarse aggregate in handling and placing. If there is an excess of water on the surface, or the mass has a tendency to flow or settle out of position after being floated, the concrete has been mixed too wet.

PLACING CONCRETE: Just before placing concrete, the sub-grade should be well sprinkled so that it will not absorb moisture from the concrete, and should be checked by the engineer or inspector to make sure that the required thickness of concrete can be placed. Checking the sub-grade may be done by the use of a straight edge or line, resting on, or stretched from the top of the side forms.

Probably the most satisfactory method of depositing the mixed concrete in position on the sub-grade is by means of a bottom dump bucket running on a swinging boom from the mixer. The boom can be swung over any position on the sub-grade, and the bucket can be run out and dumped at any point along the boom. Such equipment does not depend for economic operation upon consistency, and the concrete can be easily handled and deposited at any place on the sub-grade, necessitating but little handling with shovels. Between each change in position of the mixer a section the full width of the pavement (up to 1½ times the length of the boom), and as long as the boom, may be concreted.

When concrete is placed by means of the open trough care must be exercised to see that it is not mixed too wet, as this method of distribution depends for economic operation very much upon the consistency of the concrete. An open trough is necessarily much shorter than a boom and is more limited in action, which requires that the mixer be moved ahead more often, also that more of the concrete after being deposited on the sub-grade be handled with shovels.

When a batch mixer, not having a boom and bucket or open trough, is used, the concrete should be handled in wheelbarrows or hand carts wheeled on suitable runways. Placing concrete by means of horse carts should not be permitted as they cut up the sub-grade badly, and to get the concrete into final position requires a maximum amount of shoveling.

Whatever the method of conveying and placing, the concrete should be deposited upon the sub-grade to the required depth and for the entire width of pavement in as nearly one operation as practical so as to reduce handling to a minimum. If it is necessary to handle a large amount of material with the strike-board it will ride the concrete and thus produce a wavy, uneven surface. Attention to this matter will materially lessen the difficulty and labor in striking off the surface and will result in a very much better finish.

The excess of coarse material that accumulates in front of the strike-board should be uniformly distributed over the surface of the pavement and not left in narrow strips across the section, or placed along transverse expansion joints. An ordinary garden rake will be found useful in distributing the material that accumulates in front of the strike-board. When the strike-board is within 2 feet of an expansion joint the excess material that has accumulated in front of it should be removed with a shovel and deposited on the sub-grade in the next section. Special care should be taken to place good dense concrete along expansion joints, and all inequalities at the joints, including any small holes left after the removal of the installing device, should be filled with a mortar composed of one part cement and not more than two parts fine aggregate.

The man handling the strike-board should follow closely behind those placing the concrete, for keeping up with the strike-board will materially assist those placing concrete in depositing the required amount of material.

The placing of concrete should be a continuous operation, and stops should be made only at expansion joints. In case the mixer breaks down concrete should be mixed by hand to complete the section, or an expansion joint should be placed at the point of stopping work. Any concrete in excess of that needed to complete the section, when work is discontinued, should be spread out in a thin layer, not exceeding two inches in thickness, over the sub-grade in the next section and not piled up along the expansion joint.

The strike-board should be cut to conform to the crown of the finished surface of the pavement and should be of sufficient strength and stiffness to show no deflection at the center when supported at the ends, nor a material bowing out of alignment when in use. It should be about 2 feet longer than the width of the road, protected on the bottom edge with a metal facing and provided at each end with suitable handles.

For roads up to 12 feet in width two 2-inch by 6-inch planks, dressed on one side and both edges, spiked together, make a good strike-board, and for roads 12 feet to 20 feet in width two 3-inch by 8-inch or a 2-inch by 10-inch and a 3-inch by 10-inch, spiked together, will be found satisfactory. Two planks, well spiked together, make a better strike-board and one less likely to warp out of shape than a single piece. The strike-board should not be so heavy that it cannot be easily handled by two men, and to reduce weight and increase stiffness, it is advisable for work over 20 feet in width to use a strike-board composed of boards 2 inches or 3 inches thick, stiffened by trussing, rather than obtain the required stiffness by the use of heavier timbers.

In striking off a pavement 16 feet or less in width, where the concrete has been properly placed, two men should be able to handle the strike-board, but for wider pavements the services of a third man will be required to assist in pulling the board forward by means of a drag line fastened at its center.

The strike-board should always be worked forward about perpendicular to the axis of the roadway, and as it is moved ahead should be sawed back and forth across the road.

To produce the desired effect will require that the strike-board be passed over the surface of the concrete two or more times.

Though it will be necessary for the workmen to get into the concrete some after it is deposited on the sub-base, it is desirable that all unnecessary walking in and wading through the concrete be avoided, and under no circumstances should any workmen step upon the concrete after it is first struck off.

DISCUSSION

Mr. Boynton:—The committee has tried to point out some defects that are met in mixing and placing concrete in road work, and to suggest what might be considered good practice. In looking up what data existed on the matter of mixing, for instance, we found that there was a great discrepancy in what engineers seemed to consider and what contractors considered good practice in operating the mixer. We have undertaken to get together a little data that might act as a guide for anyone operating a mixer; and I think it is especially desirable that we develop that subject a little more fully.

Another important matter is that of consistency. The committee was a *unit in believing* that concrete as ordinarily placed in the road is mixed too

wet. The placing of concrete is more of a simple matter, and there is possibly less opportunity to go astray, providing the mixing is thoroughly done and the consistency is right. With the practice which we have assumed to be right in the first two instances, about the only practice that could be economically followed in placing is the one described in the report.

Mr. McCullough:—In regard to the mixing, I believe that the tendency is to get the concrete too wet. In nearly all the road work I have seen, I have noticed that the contractors, on their first jobs especially, use too much water.

If a spout is used merely as a conveyor, as suggested in the early part of the report, and no attempt is made to do any mixing in it, it seems as if it ought to deliver the concrete in a fairly good way. Then the only thing that the contractor would have to take into consideration would be the expense of this as compared with the use of the skip.

I think the question of the time that the concrete should remain in the drum is of more importance, and that the committee has been just a trifle weak in their recommendations in that regard. Whereas the principal mixers cited have revolutions per minute ranging from 18 to 10, it would surely seem that the one with 18 revolutions per minute would mix the concrete better than the one with 10 revolutions per minute if the concrete is allowed to remain in each mixer 45 seconds.

As a result of past experience I allow nothing but a batch mixer to be used on any work of which I have charge. I require that the maximum number of revolutions of the drum shall be 20. This is modified for different types of mixers, for in different types different kinds of drums are used. The minimum number of turns that the drum shall receive shall be 10. Now in my opinion, if we incorporate into the clause recommended by the committee, another clause limiting the speed at which the drum shall be operated, and also stating the number of complete revolutions that shall be made after all the material is in, a first-class specification for mixing concrete will be obtained.

Some mixer salesmen understand these points, others do not. Also many mixer concerns advertise the number of batches that their machines can turn out in a given length of time. Even some of our technical papers mention such points in their articles concerning the qualifications of the different kinds of mixers. To me it does not seem that the time for turning out a batch is the point of prime importance. I think when we get into the habit of letting the contractor turn out a certain number of batches in a given time, require that every batch stay in the mixer a certain length of time and be subject to a certain number of turns per minute, then with the specification regarding the amount of water, we will get the kind of concrete desired. I generally state in my specifications that the amount of water shall be such as to produce a pasty, rather than a soupy mixture; the concrete should not run freely from a wheelbarrow but should be assisted by a shovel or a hoe.

REPORT OF COMMITTEE XII

COST OF CONSTRUCTING CONCRETE ROADS

Chairman—A. N. JOHNSON
State Highway Engineer
Springfield, Illinois

JOSEPH HYDE PRATT
State Engineer
Chapel Hill, N. C.

ALBERT REICHMANN, *President*
Western Society of Engineers
Chicago

The committee on cost data begs to submit the following report:

Your committee made an attempt to secure at first hand cost data in various parts of the country where concrete road construction has been done.

Although numerous inquiries were sent out by your committee for information, there has not been received as yet any large amount of cost data except from the Michigan State Department, Wayne County, and the Illinois Highway Department.

There has already been issued by the Association of American Portland Cement Manufacturers a very complete table of cost data, and your committee decided that until more complete data was in its hands it would be but a mere duplication to publish what had already been issued.

The committee has therefore confined itself to averaging the cost of work reported in the different states, confining the comparison to the one course construction.

These data are presented herewith in the following table:

AVERAGE COST OF ONE COURSE CONCRETE ROADS

State	*Cost Per Sq. Yd.*	*State*	*Cost Per Sq. Yd.*
Arizona	$1.20	Montana	$1.83
Arkansas	.90	Nebraska	1.40
California	1.17	New Jersey	1.12
Colorado	1.25	New York	....
Connecticut	1.32	North Dakota	1.26
Delaware	1.61	Ohio	1.22
Idaho	1.09	Oklahoma	1.05
Illinois	1.01	Oregon	1.39
Indiana	1.23	Pennsylvania	1.16
Iowa	1.11	Tennessee	1.20
Kansas	1.08	Washington	1.31
Maine	1.48	West Virginia	1.32
Maryland	1.21	Wisconsin	1.06
Massachusetts	1.29		
Michigan	1.27	Average Total	$1.24
Minnesota	1.05		
Missouri	1.17	Weighted Total Av.	$1.19

There are also presented four diagrams:

Figure 8 showing the distribution of cost data on concrete roads built *1909-1912,* as reported by the State Highway Department of Michigan.

Figure 9 is a similar diagram compiled from cost data reported on the concrete road work done in Wayne County, Michigan, during 1912 and 1913.

Figure 10 is a similar diagram for the work done in 1912-1913 by the Illinois Highway Commission.

Figure 11 is the average of all the data from which the first three diagrams were made, taking due account of the relative amount of work done in each instance.

In general, it is to be noted that the labor cost is about 44 per cent while the materials cost is about 56 per cent; and that the cement cost is a little over one-fifth of the total cost of the road, while the aggregate cost is a little over one-fourth of the total cost.

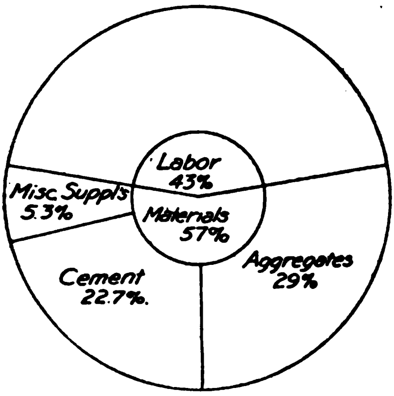

Figure 8

Concrete Road cost data on 7 Michigan roads built 1909-12. From a report by Commissioner F. Rogers of Michigan.

Av. cost per sq. yd..............$1.62
(Excluding excavation)

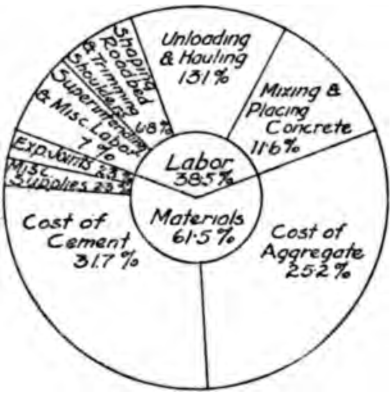

Figure 10

Concrete Road cost data, covering construction through 1913, by Illinois Highway Commission.

Average cost per sq. yd..........$.943
(Excluding excavation)

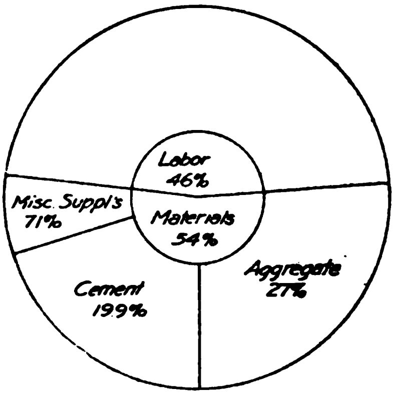

Figure 9

Concrete Road cost data on 8 sections in Wayne Co., Michigan, constructed 1912-1913.

Average cost per sq. yd.....not reported

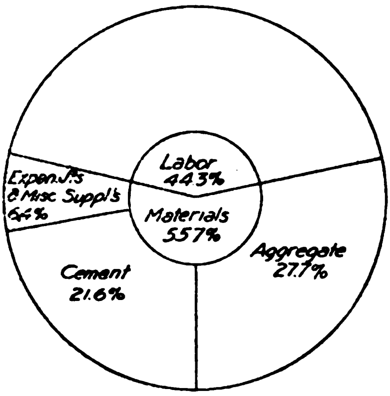

Figure 11

Concrete Road cost data; a weighted mean covering data from 7 Michigan roads, 8 Wayne Co., Michigan, roads, and 1912-13 work by Illinois Highway Commission.

DISCUSSION

Mr. Johnson:—I should like to call your particular attention to the weighted average cost per square yard which is given as $1.19. You will note that we have also presented some diagrams showing the per cent cost of the various items entering into the work. The main sub-division is between materials and labor. In the more detailed sub-division, we find that cement costs about 22 per cent, aggregate about 28 per cent, and joints, forms and miscellaneous supplies about 6 per cent. I call your attention to these percentages as making possible the study of any advocated economy in different portions of the work. For instance, we may be offered a special device—perhaps a rather high-priced affair that is going to cut the cost of that particular part of the work in two. In studying the percentages, we may find, perhaps, that the total cost of this particular portion of the work does not total over 5 or 10 per cent; so that the most we may be able to save on the job is 2 or 3, or at best, 5 per cent. Now this device may be so high-priced that it would have to be used on a great number of jobs to possibly save its cost and make its purchase justifiable.

It did not seem to us that the available data on the cost of two-course work was in digestible shape, so that we were unable to draw any definite conclusions. The variation on two-course work is so much greater than on one-course work, that it is difficult to draw comparisons. I can say, however, that two-course work in general is more costly than one-course work, but the extent of this difference I am unable to give.

Mr. Boley:—I am able to give you some figures on the two-course pavements laid in the city of Sheboygan. The costs ran from $1.20 to $1.35 per square yard. The lowest cost we ever had was $1.20. This occurred in 1911 when the price of cement was comparatively low. My experience has only been with city streets, which, in this case, were 30 feet wide, 8½ inches thick in the center and 6½ inches on the side.

REPORT OF COMMITTEE XIII

THICKNESS, CROWN AND GRADES FOR CONCRETE ROADS

Chairman—LEONARD S. SMITH
In Charge of Roads and Pavements, University of Wisconsin,
Madison, Wisconsin

EARLE R. WHITMORE
City Engineer
Port Huron, Mich.

T. R. AGG
Ass't Professor in Civil Engineering
Iowa State College, Ames, Iowa

Even the hurried and incomplete examination of the literature concerning thickness, crown and grades of concrete pavements discloses the fact that a very considerable variation in practice has existed in the past. In fact, in view of the many local factors which must and should control such details, we do not see how in the future it will be possible to standardize such matters, except to a limited extent.

The observations of your committee indicate that future failures in concrete pavement are more apt to result from a lack of faithfulness and skill in the selection of materials and their proper incorporation into the pavement in a workmanlike manner than they are from improper details of design. It must be admitted that the greatest obstacle to securing excellent pavements of any type is the difficulty in securing competent inspection. This is particularly true of concrete pavements because of past conditions too well known to need discussion here, but growing out of the careless and unskillful manner in which concrete for pavement foundations has been constructed.

A review of present practice of any art is usually illuminating and in case of a comparatively new structure—like the concrete pavement—is likely to be of considerable value.

THICKNESS

The thickness of the concrete pavement is controlled by many factors, such as condition and character of the subgrade, drainage, traffic, climatic conditions, width of pavement, etc. Three distinct types of cross-sections are in general use:

A. Uniform thickness of concrete for all widths of roadway, and consequently with the same amount of crown in the foundation as in the surface.

B. Roadways in which the concrete is thicker at the center than at the edge but in which some crown is given to the foundation.

C. Concrete roadways in which the concrete is thicker at the middle than at the edge, but which are built upon a flat subgrade. This type seems to be fast gaining in favor.

In one of the publications of the Association of American Portland Cement Manufacturers, entitled "Concrete Highways," may be found a table giving data on the thickness of about 600 concrete pavements in this country. In Appendix I may be found some additional information on this point, collected by the committee.

It will be seen from these data that the thickness of concrete pavements varies from 6 to 8 inches at the crown line and from 5 to 8 inches at the edge. The necessity for the greater thickness is perhaps more urgent in the northern than in the southern parts of the United States, because of the greater extremes of temperature. Because of the growing tendency to increase the size of the loads, it seems reasonable to suppose that we have not yet reached the extreme limit of thickness required.

Because of the fact that the members of this committee have had their attention directed chiefly to the conditions obtaining in the northern states, it is not without some misgivings that they suggest the following as conforming to the best practice:

1. Where the width of roadway is not greater than 16 feet, with a porous subsoil, subgrade in good condition and well packed and with loads not exceeding six tons, including the vehicle, a thickness of 5 inches at the edge of the slab and 7 inches at the center is sufficient without reinforcement, using slabs not greater than 16 feet square.

2. On clay soil and the above general conditions artificial drainage should be provided and reinforcement used (¼ to ½ pound per square foot), placed 1½ to 2 inches from top surface; and slabs made not larger than 16 feet square and not less than 6 inches thick at edge of slab and 8 at the center.

3. Where the roadway is in excess of 16 feet with loads of 6 to 10 tons but with the other general conditions as described in (1), the crown of the pavement should have a thickness of 8 inches and the edge 6 inches. Under such circumstances reinforcement will usually be considered necessary and economical.

CROWN

Unlike some types of pavements, those of concrete are undamaged by water, unless it should find its way to the subgrade. However, since even thin sheets of water or ice on the surface of any pavement are objectionable, a sufficient crown must be provided to insure the unwatering of the pavement. Theoretically, with perfectly surfaced concrete, only a very slight side fall is required to accomplish this. Practical experience in such construction, however, has demonstrated the great difficulty in preventing small imperfections and depressions in the surface, therefore sufficient cross fall must be provided to insure drainage. The difficulty of accomplishing this is increased because of the suspension of large amounts of dust in the street water.

Attention is directed to the fact that on city streets with side curbs we face a different problem from that found in a narrow country road without curbs. In the city street the crown must not only be sufficient to cause the water to run from the center to the side of the pavement, but also enough to insure that an undue proportion of the pavement shall not be covered by water. This requirement is aided if the pavement is given a "peaked" crown, i. e., say ⅞ of the total rise at ¼ distance from center to curb, and ⅝ at half the distance.

The small crown that may be properly used on concrete pavements is justly considered an important merit of this type of pavement. Data have been collected which seem to show that in the case of uniformly thick concrete pavements, the amount of central longitudinal failures has varied directly with the amount of crown. To a lesser extent this would be expected of the other types, thus furnishing an additional reason for the adoption of a minimum crown.

In Appendix II will be found the practice regarding crowns in about thirty cities, from which it appears that the minimum crown used on streets is 1/160 of the width of the road and the maximum 1/48. With few exceptions, the crown varies between 1/70 and 1/100 of the width. When the climatic conditions will allow, it is our opinion that a crown of 1/100 of the pavement width represents present best practice. The use of the high crowns has in large part resulted from past experience with other types of pavements where high crowns were really required. We are of the opinion that in future construction, as methods of handling materials are improved and contractors become more experienced, engineers should not hesitate to specify as low a crown as 1/150 part of the width. Indeed, this has already been done to some extent.

The purposes of this report do not contemplate a discussion of the subject of crown formulas, but a few suggestions may not be out of place.

The present common practice of specifying an arbitrary crown ratio for streets varying in width by 75 or more per cent, and this, too, quite independent of the street grade, does not appear to be founded on any reasonable basis. Unless local conditions forbid, a smaller crown should be designed for a heavy than for a light grade street. Tables have been published which give the allowable crowns as a function of the grades. This whole matter would seem to deserve much more attention than it commonly receives.

GRADES

The committee have been unable to find any reliable data on the relative slipperiness of concrete pavements. It is greatly to be regretted that such information is not at hand. In view of the ease with which tests of this nature could be made and the importance of such knowledge in the design or selection of pavements, we recommend to this convention that experiments along this line be undertaken.*

From such observations as we have been able to make, we see no reasons why a concrete pavement, properly finished, may not be used on grades as steep as any other hard surfaced pavement, and on steeper grades than either wood or asphalt. On steeper grades than 3 or 4 per cent shallow corrugations in the surface will be found of much assistance—in fact, with grades of 5 per cent and over, a real necessity.

*Perhaps such work can best be done under the guidance of some University because of the need of unbiased and impartial tests.

APPENDIX I

DATA ON THICKNESS, CROWN AND GRADES FOR CONCRETE ROADS

One Course Pavement

Location of Road	Mixture of Concrete	Thickness in inches at middle	Width in feet	Kind & Size, Expansion Joints	Crown in Inches	Service Reports
Michigan Ave., Wayne Co., Mich.	1-1½-3	7	16-20	Baker Plates & tar paper 25 ft. apart	1.9 to 2.4 1/100 of width	
Grand Rvr. Rd. Wayne Co., Mich.	1-1½-3	7	16	Ditto	1.9 1/100 wd.	
D Street, So. Omaha	1-2½-5	8	30	Spcd. 30 ft.		
Polk St. Memphis, Tenn.	1-2¼-4½	6	30	50 ft. ¾" board filler	8 1/45 wd.	
Jennings St. Sioux City, Ia.	1-3-4½	5	38	25 ft.		Satisfactory
Front St. Boise, Idaho.	1-3-7	8	69½	25 ft.	9 1/93 wd.	Satisfactory 2½ yrs.
22nd. Street Kansas City.	1-2½-5	6	26	None in 150 ft.		10% grade.
Bonneauville Rd. McSherrystown, Penn.	1-3-5	5	16	50 ft.		Satisfactory.
Cemetery Rd. Red Oak, Iowa.	1-2-4	6	14	16 ft.	3 1/56 wd.	
State St. Bettendorf, Ia.	1-2½-4	6	20	12½ ft.	Slope 3" 1/80 wd.	
Hillsboro Rd. Greenville, Ill.	1-2½-5	8	16	25 ft.	Slope 1" 1/192 wd.	Satisfactory.

Two Course Pavement

Location of Road	Mixture of Concrete	Thickness in inches at middle	Width in feet	Kind & Size, Expansion Joints	Crown in Inches	Service Reports
Adams Ave. Mason City, Ia.	1-2-5 base 1-2 top	5 base 2 top	30	25 ft.		
County Rd. Coshocton, Ohio.	1-2-4 base 1-1½ top	5-1	18	10		
Main Street, New Hampton, Ia.	1-2-5 base 1-2 top	5-2	51			
Cemetery Rd. Washington, Ia.	1-2½-5 base 1-1½ top	5-2	9	20 ft.	1½ 1/70 wd.	

Two Course Pavement (Cont'd)

ation of Road	Mixture of Concrete	Thick-ness in inches at middle	Width in feet	Kind & Size, Exp. Jts.	Crown in Inches	Service Reports
as St. y, Mo.	1-2-5 base 1-2 top	5 base 1 top	N.B. 28 to 39	50 ft.	3 1/112 to 1/156 of width	
: d, Del.	1-2½-5 base 1-1½ top	5-1	28	100 ft.	7 1/48 wd.	
y, e, Wis.	1-3-5 base 1-1½ top	6-1¾	28 to 56	50 ft.		
St. n, Ia.	1-2-5 base 1-2 top	4-2	30	40 ft.		
Iowa.	1-6 (gravel) base 1-2 top	5-1½	30		5 1/72 wd.	
: ian, Mont.	1-2-4 base 1-1-1 top	5½-1½	63	100 ft.		
. du Lac, Wis.	1-2½-5 base 1-1-1 top	5-1½	30	50 ft.	3 1/120 wd.	Reinforced 18' middle.
ville, s.	1-2-3½	6	15	50 ft. plates	⅜" per foot	
d, s.	1-2-3½	6	9	"	"	
eld, s.	1-2-3½	8-6	18	"	"	
s.	1-2-3½	7-6	16 to 20	"	"	
s.	1-2-3½	6	8	"	"	
lle, s.	1-2-3½	6	16	"	"	
owa.	1-2-4	7½-6	28	25 ft.	1½ 1/224 wd.	
ke.	1-2-4	7½-6	16	25 ft.	1½ 1/128 wd.	

APPENDIX II.

DATA ON CROWN USED IN CONCRETE PAVEMENT

City	Width of Street or Alley.	Crown of Street inches	Ratio of Crown to Width Street
Davenport, Ia	Alley 13-16 ft.	4 depressed	1/40-1/50
" "	" 20	5 "	1/50
" "	Street 24-32	6	1/50-1/70
" "	" 52	8	1/80
Dubuque, Ia	Alley 10	2	1/60
" "	" 20	5	1/50
Cresco, Ia	Street 29½-42	6	1/60-1/83
Vinton, Ia	" 46	6	1/90
Council Bluffs, Ia	" 20	1½	1/160
Clear Lake, Ia	" 50	8	1/74
Cedar Rapids, Ia	" 16	2	1/96
" "	" 18	3	1/72
Mason City, Ia	Alley 33	6 concave	1/66
" "	Street 18	3	1/72
" "	" 30	6	1/60
" "	" 40	8	1/60
" "	" 66	8	1/100
" "	" 46	9	1/60
Le Mars, Ia	" 30	5	1/75
Rockville, Ind	" 26	4	1/78
Menominee, Wis	" 32-42	4	1/96-1/126
Fond du Lac, Wis	" 24	3½	1/80
" "	" 27	4	1/80
" "	" 30	4½	1/80
" "	" 32	5	1/77
" "	" 40	6	1/80
Newton, Ill	—	—	1/100 standard
Liberty, Mo	" 28-39	3	1/112-1/156
Mulford, Del	" 28	7	1/48
Wayne Co., Mich	" 16	2	1/96
Ann Arbor, Mich	" 30	6	1/60
Bay City, Mich	" 24	4	1/72
" "	" 36	7	1/61
Grand Rapids, Mich	Alley 18	2	1/108
" "	Street 22	5	1/53
" "	" 15	2	1/96
Kalamazoo, Mich	" 67	9	1/88
" "	" 42	6	1/84
Owosso, Mich	" 60	9	1/80
Toronto, Can	" 16	2	1/96
Brantford, Can	" 24	5	1/57
" "	" 26	6	1/52
" "	" 40	4	1/120
Edmonton, Can	" 27	5	1/65

DATA ON CROWN USED IN CONCRETE PAVEMENT (Cont'd)

City	Width of Street or Alley ft.	Crown of Street inches	Ratio of Crown to Width Street
;uelph, Can............	—	—	1/60
ondon, Can...........	Street 24	3	1/96
laisoneuve, Can........	" 44	5	1/105
'eterborough, Can......	" 25	3	1/100
Legina, Can............	" 32	7	1/55
t. Thomas, Can........	" 18	3	1/75
Vindsor, Can...........	" 24	5	1/57

DISCUSSION

Professor L. S. Smith:—I should like to commend the idea brought out n the report concerning dished foundations. At first, of course, we revolt rom that, because of the fact that it is bound to add to the expense of our ighways. However, it is worth noting that as we have made progress in his country in the construction of pavements, such progress has nearly always een accompanied by a corresponding increase in the cost. The time is past vhen we can consider that this is the greatest obstacle. What the people re going to demand very soon will be the best form of pavement, and it is p to the engineers to design that form. I have all the greater confidence in he report on the dished foundations in view of the fact that the investigations ave been made with full sized pavements, rather than as laboratory experinents.

I am not sure but that in the northern part of the southern states greater xtremes of temperature are likely to occur because of the lack of snow; hat is, the pavements do not have the protecting blanket of snow that covers he pavements in the northern states in the coldest weather.

I was very much impressed with the fact that the European practice, lmost universally, is for a much thicker foundation on all of their pavements han those which we use in this country. In cities as large as Chicago, Europeans do not hesitate to use 10, or even 12 inches of concrete as a oundation for their pavements. The reason for this is not hard to see if ve note the size of the loads that these pavements have to carry.

In Fond du Lac, Wisconsin, there is a pavement reinforced with No. 7 vire mesh. It was obvious to me from the investigation that I made there hat this wire was too light, as it did not suffice in greatly reducing the number of cracks and only to a small extent in reducing the size of the cracks. This vould seem to indicate the necessity of heavier reinforcement than has been pecified.

Mr. F. P. Wilson:—In the past five or six years I have designed and constructed approximately 320,000 square yards of concrete pavements for city streets in Iowa and other states in the northwest. A two-course pavenent has been used throughout. This was made 7 inches in thickness, the bottom or base of concrete 5 inches in thickness, and the top or wearing surface 2 inches in thickness; using the same thickness of slabs on residence

as well as on business streets. In city streets the traffic is so steady that it is spread over the entire surface of the pavement, and for that reason we have made the slabs the same thickness from curb to curb.

A flat crown concrete pavement in a city street does not properly take care of the drainage, especially where there are no storm water sewers. Nor does it have the sightly appearance of one that is curved slightly between the crown and the quarter with an increased curvature 5 or 6 feet out from the curb line. And further, the flat crown does not match up well with the pavement which it joins. For these reasons I have constructed the crown of the concrete pavements the same as the crown of the existing pavements.

On country roads most of the travel is along the center of the roadway, so that I think it is permissible to decrease the thickness of the slab on the side. By having a flat sub-grade, the necessary crown can be obtained by making the center of the slab 1½ inches to 2 inches thicker than the sides. This crown, though flat, is admissible on account of the width of roadway paved being narrow, and because the drainage is usually taken care of outside of the portion paved.

A concrete pavement properly constructed, and the surface finished in a workmanlike and up-to-date manner, can be used on any street whether the grades are heavy or light, and still have a surface that is less slippery than that of any other pavement known. I have used grades as steep as 9.5 per cent without corrugating the surface. Although this was on streets where the traffic was heavy and constant, I have not heard of any complaint about the pavement being slippery or impassable. I do not corrugate a pavement on a grade under 10 per cent as I think such construction is bad. The corrugations are lines of weakness that are likely to cause the pavement to break down. The proper surface is obtained by the use of a wooden float made of coarse-grained, soft wood. This is sawed out of a stick or block of wood with a rip saw, which leaves a rough surface. Such a float, when properly used, will produce a surface on the concrete pavement which is smooth and sightly, and still rough enough to produce sufficient traction for horses and vehicles.

Mr. Morse:—Although all the recommendations for good aggregate, clean sand, and proper reinforcement are necessary, these do not seem to me to give a solution for preventing cracks. For this purpose, a slab which is a self-sustaining beam should be designed. According to calculations made on this basis I came to the conclusion that the proper thicknesses for pavements, 8, 12, 16, 20 and 24 inches wide, were respectively, 6, 7, 8, 9 and 10 inches. To me it is as rational to make a 10-foot pavement 8 inches thick as to make a 20-foot pavement 7 inches thick. The first is a waste of good material, and the second leads to certain failure. In other words, the thickness of the slab should increase as the width of pavement increases.

Mr. Warren:—Investigations seem to indicate that we have in the past been building our pavements too thin, which leads me to think that the committee's recommendation that the thickness should increase directly as the width is very important. One of the reasons why the pavements with dished sub-grades have given such success is that a crowned slab on a dished foundation is necessarily thicker at the center than a slab on a flat or crowned sub-grade. Where people have begun to construct dished sub-grades, they have recognized the necessity of applying scientific principles in the design of pavements.

In my opinion good results cannot be obtained by using the figures of the Association of American Portland Cement Manufacturers referred to in this report. I would recommend, therefore, that in order to get the right thickness and a scientific design, those figures be stricken out.

Mr. Wig:—When a slab that is laid on the dished sub-grade expands, it will have to extend against gravity; it will be restrained more than if it were simply on a flat sub-base and therefore will not move as far, but will put greater compressive stresses in the concrete. Then in contracting it will simply relieve this stress, because it will not have to contract as far as it otherwise would with the sub-grade flat or crowned. In addition, such a slab will have a tendency to wedge itself into the sub-grade, which tendency ought to keep the sub-grade more firm than it otherwise would be.

Mr. Boley:—On our 30-foot roadways in the city of Sheboygan, we have a total thickness of 8½ inches in the center and 6½ inches on the side for the two-course concrete pavements. The usual crown is from 3 to 4 inches. In our work on macadam streets, of which we have a large number, the custom was to give a larger crown on hills than we did on level streets, in order to shed the water to the sides as quickly as possible. That would not be necessary in the case of concrete streets, because there the water will not stand. For such streets the amount of crown should decrease as the grade increases.

REPORT OF COMMITTEE XIV

PROPORTION AND CONSISTENCY OF MATERIALS FOR CONCRETE ROADS

Chairman—C. U. Boley
City Engineer
Sheboygan, Wis.

C. C. Widener
City Engineer
Bozeman, Mont.

George A. Dingman, Engineer
Board of County Road Commissioners
Wayne County, Detroit, Mich.

Any specification for proportion and consistency of materials for concrete pavement must be general and suggestive, rather than mandatory, adaptive, or rigid. The representatives at this conference come from all parts of the country, from districts whose geological formations furnish concrete materials differing widely in their physical and chemical composition, and also furnish soils of equally wide characteristics upon which these pavements are to be laid.

From these geological formations we get as materials for concrete pavements all varieties of rock, gravel and sand, as from the cement manufacturers we get the various brands of cement to bind them together. The cement problem has been standardized but the aggregate problem has not. Each locality must conform its practice to meet local conditions of material, soil, climate and traffic.

A rule that may be admirable for a granite district, furnishing hard cubical well graded rock, may fail utterly if applied to a district whose only resource is soft limestone or gravel that washes into shape instead of fracturing into sharp angled cubes.

Ideal paving concrete is a combination of perfect mineral aggregates and cement in such proportion as will give the greatest possible density, and in which, for economical considerations, the cement content is the least possible consistent with ultimate strength and durability. Relative cost of material may justify greater thickness of base with less crushing or tensile strength per unit area.

CONCRETE PAVEMENTS

PROPORTIONS OF CONCRETE

For the base of two course pavement, with sound hard limestone or gravel having 40 per cent voids, screened washed bank sand having 30 per cent voids, and Portland cement passing the standard specifications of the American Society for Testing Materials, the proportions should be one (1) sack of cement, two and a half (2½) cubic feet of sand and five (5) cubic feet of crushed stone or gravel, the aggregate having been so proportioned as to eliminate the voids as far as practicable.

For single course pavement the proportions should be one (1) sack of cement, two (2) cubic feet of sand and not more than three (3) cubic feet of crushed stone or gravel.

*CONSISTENCY OF CONCRETE

The amount of water should be such as to make the concrete plastic and still retain its shape, such as is commonly called a quaking mixture. Methods

(*See report Committee XI, Mixing and Placing Materials for Concrete Roads, page 138.)

and distance of transportation before depositing will be factors in determining the amount of water used; concrete deposited from buckets, traveling along a boom, may have more water added than when wheeled for a considerable distance in barrows or carts. In the latter case the unavoidable shaking brings the lighter materials to the surface and causes a segregation of the materials, which results in an improper mixture when deposited.

PROPORTIONS OF WEARING COURSE

The fine aggregate for wearing course shall be mixed with Portland cement in the proportion of one (1) sack of cement to two (2) cubic feet of the graded mineral aggregate. While this furnishes a considerable excess of cement we get greater impermeability.

CONSISTENCY OF WEARING COURSE

Sufficient water shall be used with the fine aggregate to form a mortar that will work easily under the template and at the same time retain its shape when deposited.

DISCUSSION

Mr. Boley:—I want to call your attention to the necessity for the latitude that must be allowed in any specification for proportion and consistency of materials. The matter of consistency has been taken up in a former paper in a manner somewhat similar to that herein presented. I will say that we have had cases on our streets where the material had to be moved some distance. We found that the shaking of the vehicle in which it was transported, whether a wheelbarrow or a cart, would cause most of the fine material and water to be brought to the surface. Then, when it was dumped out of the barrows, the water would soak into the sub-grade and leave the top too dry. That is, too wet a mixture, especially when it has to be transported some distance, segregates the materials.

Although our report calls for 1 sack of cement to 2 cubic feet of a graded aggregate as a suitable mixture for the wearing course, I would say that the mixture used on most of our streets was even a little stronger in cement than that. We have, say, 40 per cent cement and 60 per cent of the graded aggregate.

Mr. Tunnicliff:—I would like to call the attention of the Conference to the specifications for aggregate given in the last paper. These are based on the percentage of voids. That does not seem to me to be in accord with the recommendation of Committee No. 3, where the specifications were made for the amount of material which would pass certain sized screens. Of course there is a relation there, but I am not personally satisfied whether the two methods are identical.

Mr. Webster:—It has been a matter of great interest to us in DeLand, Florida, to place our materials quickly enough from the mixer. The rule that we are now using in our sidewalks is to keep the mixer close to the work, and as we use a rather small batch machine, the material is not transported in wheelbarrows at all. It is simply turned down to the platform and handled by shovels directly into the forms. I offer this as a suggestion, for it may be possible in some of this road work to handle the material in the same

way. In our work everything is put in place within 60 seconds from the time it is mixed.

Mr. Boorman:—In every section of the country different problems arise affecting the desirability of the proper kind of pavement to use. In Cook County, with the cement produced virtually on the roads, it would seem as though concrete roads should be the best construction from an economical as well as a practical standpoint. I do not see how the use of expansion joints and asphaltic coatings can be avoided there. But in a climate of an even temperature like that of Panama, which creates no tendency towards expansion and contraction, such joints and coating may well be omitted. This was actually done in that place, for the engineers decided to omit the use of a bituminous filler that had been sent by the Government.

Mr. Hewitt:—In the several years' experience that I have had in putting in concrete, I have tried both the method of placing the material direct from the mixer and from carts. It seems to be the opinion here that the concrete should be rushed immediately into the work. In order to do that the material must be distributed along the road. This means a mixer that not only mixes the concrete and deposits it, but one that also moves along the road at the same time, or at frequent intervals. Although I own such a machine myself, I am still in favor of the proposition of depositing the concrete from a cart. With such an arrangement the mixer can be set at the stock pile and its batches dumped into a cart and transported 500 or 600 feet up the road and dumped. The surplus water that comes to the top can certainly be disposed of somehow. After the cart is dumped the concrete can be spread out and worked, for there will be enough moisture there to flush the surface of it.

I would like to suggest placing the material on planks in order to keep the stock clean, inasmuch as every one seems to agree that that is very essential. This does not involve a large expenditure, unless the number of stock piles is very great, in which case the cost would be too excessive for the contractor to bear. This is another argument in favor of few stock piles, infrequent movements of the mixer, and transporting the material by carts.

Mr. Gerber:—I would like to ask the engineers of Sheboygan and Mason City, Iowa, if in their two course work they mixed the concrete for the bottom course with less water than that for the top course, especially where reinforcement was placed between the two courses. Of course, I understand that as in sidewalk work the top course must be placed before the first course has entirely set; but I have heard considerable discussion as to the desirability of the bottom course being drier than the top course.

Mr. Boley:—In our work we usually make the bottom course drier than the top course.

REPORT OF COMMITTEE XV

FORM OF SPECIFICATIONS FOR CONCRETE ROADS

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St. Paul, Minnesota

Your committee submits the following suggestions for a proposal, contract and specifications for concrete road construction.

I. PROPOSAL

1. INSTRUCTION TO BIDDERS. *Note.* This paragraph may include a detailed statement of the manner of bidding on the work which is included in the contract, the work or materials incident to the construction that are furnished by other than the contractor, provision for mailing bids and name and address of official who is designated to receive bids, time and place of opening of bids, prescribed form of bidding blank, provision that bids must be sealed, statement making the proposal a part of the contract if accepted, etc.

2. LOCATION. *Note.* Insert a specific description of the proposed improvement in such a form as may be required by law or may best indicate to the contractor the location and extent of the proposed improvement.

3. ESTIMATE OF QUANTITIES. *Note.* Insert a form of estimate of quantities which will be consistent with the manner of bidding. If lump sum bids are taken, then give total quantities. If unit prices are called for, then give quantities of each class of work and material.

4. CERTIFIED CHECK. *Note.* State the amount and form of certified check or other deposit required with the bid, and what provisions are made for returning certified check or other deposit to unsuccessful bidder.

5. BEGINNING AND COMPLETION OF WORK. *Note.* Name a date for the beginning and a date when the work must be completed; provide for completion of the work by day labor if contractor makes unsatisfactory progress; also provide the amount of damages accruing for each day of overtime if the contractor fails to finish on time.

6. PLANS AND SPECIFICATIONS. *Note.* Provide for the identification of the plans that accompany the specifications, the scope of each, and which shall govern in case of discrepancies.

7. EXTRA WORK. *Note.* Provide for extra work to be done only upon written authority from proper officials at a predetermined price, or as may be deemed advisable.

8. PRICE SHEET. *Note.* The price sheet should include suitable forms in which the bidder may insert his prices, the form being arranged for the manner of bidding determined upon. The price sheet may include a statement to the effect that the bidder has examined to his satisfaction the plans and specifications and the site of the proposed improvement. There should be on the price sheet a signing place so that the bidder can sign regardless of any provision elsewhere in the specification for a signature.

II. CONTRACT

9. CONTRACT. *Note.* Any suitable legal form may be used. The following form of contract or some modification of it is in quite general use:
County of......................
Town of......................

For the improvement of the .... Road (or Street) commencing ....
and extending thence .... in accordance with the provisions of sections........inclusive, of the statutes, and of the specifications annexed hereto, made and concluded, subject to the approval of the ...., ..., this .... day of ...., 191..., by and between .... party of the first part, and .... party of the second part, hereinafter called the Contractor.

WITNESSETH: That in consideration of.................... (insert price sheet or other statement of contract prices) to be paid by the party of the first part in the manner following, to wit: ....
the said Contractor agrees with said party of the first part at his own proper cost and expense, to do all the work of said improvement according to the provisions of the plans herein referred to and of the specifications hereto attached and made part hereof, and subject to all the terms and conditions of said specifications, and to furnish all labor, tools, machinery and materials except .... necessary therefor.

IN WITNESS WHEREOF, the parties hereto have set their hands the date herein named.

III. GENERAL CLAUSES

10. WORK TO BE DONE: MATERIALS AND TOOLS. *Note.* A detailed statement of the work required under the contract and the materials and tools must be furnished by the contractor, including a statement as to what tools or materials, if any, will be furnished by the party of the first part and on what terms.

11. NOTICE OF BEGINNING AND COMPLETION OF WORK. *Note.* Provide that engineer or other official be notified in advance of the beginning of the construction of the work so that suitable arrangements can be perfected for inspection. Also provide for a written notice to engineer or other official that work is ready for final inspection.

12. LAWS AND ORDINANCES. *Note.* Provide for observance of state, county or municipal laws or ordinances applying to work in hand, protection of traveling public from danger of injury or loss of life by means of suitable warning signs, red lights and barriers.

13. PROTECTION OF WORK DURING CONSTRUCTION. *Note.* Provide that contractor must protect all parts of work whether complete or incomplete until final inspection and acceptance; also provide that if natural or artificial drainage along or across the improvement is interfered with, the water shall be taken care of without causing damage to property or injury to persons.

14. PAYMENTS. *Note.* Provide for the amount and frequency of partial estimates and for final estimate and acceptance. Quantities of various kinds of work shall be paid for according to the engineer's measurements.

15. BOND. *Note.* Amount of bond should be determined by engineer unless fixed by statute. Kind of bond and time allowed for filing should be given.

16. INCOMPETENT OR DISORDERLY WORKMEN. *Note.* Workmen who are incompetent for work they are doing, or who deport themselves in a manner to annoy the public, must be discharged upon request of the engineer or inspector.

17. WORKMEN'S QUARTERS. *Note.* Provide that temporary quarters arranged for workmen be maintained in sightly and sanitary condition, and that all conveniences that are provided be subject to inspection and regulation by the engineer.

18. DUTIES OF INSPECTOR. *Note.* The duties assigned to the inspector and the authority given him are not the same in all cases, and one or the other of the following may be used:

(a) The inspector may have no authority to pass on the suitability of materials or of work done, but may merely report what he sees to the engineer who reserves the right to finally pass on such matters himself.

(b) The inspector may be given authority to finally pass on the question of materials and the sufficiency of the work, in which case acceptance by the inspector is equivalent to final acceptance of the work.

In either case the clause defining the duties of the inspector should clearly indicate their scope.

19. DEFINITIONS. *Note.* The status of each person or official body concerned with the work should be clearly defined. Usually there will be four parties interested as follows:

(a) Party of the first part.
(b) Party of the second part.
(c) Inspector.
(d) Engineer.

20. PLANS ARE A PART OF CONTRACT. *Note.* This clause should identify the plans and specifically provide that the plans so identified are a part of the contract. The identification may be made by means of title, number or other suitable designation so that it is inclusive and exclusive. Work done to be true to alignment, grade and cross section shown on plans.

21. ENGINEER'S GRADE STAKES. *Note.* The necessary grade and line stakes are to be set by the engineer. The stakes and laborers used in setting shall be furnished by contractor. If disturbed, contractor shall pay actual cost of re-setting.

22. ENGINEER AS REFEREE. *Note.* In case of dispute between the party of the first part and party of the second part the engineer should

be the referee and his decision should be final and binding on both alike. It is conceded, however, that his decision would be subject to review by the courts, providing either party was unwilling to abide by his decision. Such recourse, it is believed, would surely be had, at least on small matters.

23. Imperfect Work or Material. *Note.* Materials not meeting the specifications are to be removed from the site of the work immediately upon being pointed out to the contractor. Imperfect work likewise shall be remedied or replaced by approved work immediately upon being brought to the attention of the contractor by the proper official.

24. Changes in Plans. *Note.* Changes in plans may be made when necessary, but if productive of increased cost, allowance shall be made for such increased cost in an amount to be agreed upon in writing before the changed work is started. Deduction to be made in like manner. Changes in plans so made shall not invalidate contract.

25. Contractor's Liability. *Note.* Contractor must file with his bond evidence of having taken liability insurance to protect his laborers and the public during the construction of the work, unless liability laws of states afford protection in some other manner.

26. Guarantee. *Note.* Any desired guarantee clause may be inserted.

27. Sub-letting Contract. *Note.* Contract shall be sublet only upon approval of the party of the first part or the engineer as may be deemed advisable in individual cases.

28. Preserving Monuments and Landmarks. *Note.* Contractor must preserve corner stones, bench marks, or other monuments encountered in the progress of the work until they are suitably referenced by the engineer, when they may be removed if necessary in order to properly prosecute the work.

29. Instructions to Superintendent. *Note.* The contractor shall designate some one as superintendent with authority to deal with the engineer if the contractor himself is not present. Instructions so given to be considered as having been given to the contractor himself.

IV. SPECIFICATIONS FOR ONE OR TWO COURSE CONCRETE PAVEMENT

USE CLAUSES AND CLAUSE NUMBERS ENCLOSED IN [] FOR TWO COURSE WORK ONLY

30. Materials. (a) *Cement.* Specify that quality and tests shall be in accordance with the standard specifications of the American Society for Testing Materials.

(b) *Coarse aggregate for lower course.* Specify kind, quality, grading and tests.

(c) *Fine aggregate for lower course.* Specify kind, quality, grading and tests.

[(d) *Aggregate for wearing course.* Specify size, grading and tests.]

(d) [(e)] *Use of pit run gravel.* Prohibit or limit its use as deemed *advisable.*

(e) [(f)] *Water.* Provide that it be free from appreciable quantities of sewage, acids, alkalies, clay or loam.

(f) [(g)] *Bituminous filler for expansion joints.* Specify kind and character desired.

(g) [(h)] *Bituminous material for surface coating.* Specify kind and quality.

(h) [(i)] *Protection plates for expansion joints.* Specify size and character of plates or other protection device.

(i) [(j)] *Reinforcing metal.* Specify kind, size and quality.

(j) [(k)] *Gravel or chips for bituminous surfacing.* The material used for dressing the surface after the bituminous material has been spread should consist of good, clean, hard torpedo gravel or three-eighths inch screened chips obtained from trap or equally hard rock.

31. Machinery. (a) *Concrete mixer.* If special kind or type desired, so specify.

(b) *Roller.* Specify kind and weight of roller to be used for compacting earth foundation.

32. Earthwork. (a) *Excavation.* Method of working and disposal of materials to be specified as desired.

(b) *Embankment.* Method of placing and compacting to be specified as desired.

33. Roadbed. *Note.* Define and describe its method of preparation.

34. Shoulders and Side Roads. *Note.* Define and specify method of construction.

35. Under Drains and Lateral Drains. *Note.* Specify type, dimensions and method of constructing the desired system of drains.

36. Side Forms. *Note.* Provide for rigid side form planking properly set to line and grade. Metal forms to be used if desired, and if used must be heavy and rigid.

37. Thickness of Concrete. *Note.* Concrete in each course shall be of thickness shown on plans, no extra allowance for extra thickness, no less thickness to be accepted.

38. Proportions for Concrete. *Note.* Specify the desired method of measuring aggregates for concrete and give proportions determined upon for the work.

[38. Proportions of Concrete for Lower Course. *Note.* Specify the mixture and method of measuring aggregates for the concrete for the lower course.]

[39. Proportions of Concrete for Upper Course. *Note.* Specify the mixture and the method of measuring materials for the upper course.]

39. [40.] Placing Reinforcing Materials. *Note.* Describe the manner of placing the reinforcement and the desired precautions to insure that the operation will be done at the time and in a manner which will secure a good bond.

40. [41.] Placing Expansion Joints. *Note.* Protection plates, if used, to conform exactly to cross section shown on plans, and to be carefully set with a clear open joint entirely through the pavement which may, however, be made of felt, paper, or by a metal plate which will subsequently be withdrawn. In latter case opening must be filled with desired filler.

41. Mixing and Placing Concrete. *Note.* The method of placing the concrete will depend upon whether the pavement is plain or reinforced. The provisions in the two cases may be as follows:

(a) For plain concrete work the concrete for the entire thickness of a road may be placed at one time. It should be carefully spread without a separation of the aggregates, and be finally struck off accurately to the desired cross section. Roadbed to be saturated with water before the concrete is placed. Provide against cold weather concreting.

(b) In case of reinforced concrete construction provide for placing as in (a), with such modifications as are necessary to accommodate the particular type of reinforcement used.

[42. Placing Concrete for Lower Course. *Note.* Describe the manner of placing, spreading and shaping the concrete for the lower course.]

[43. Placing Concrete for Upper Course. *Note.* Describe the manner of placing and shaping concrete for the upper course including precautions to be taken to secure a bond between the upper and lower courses.]

42. [44.] Finishing the Surface. *Note.* Surface shall be finished with wood floats and marked in any manner desired.

43. [45.] Beveled Edges. *Note.* If edges are to be beveled, specify extent and when the work is to be done.

44. [46.] Curing the Concrete. *Note.* Specify the desired protection against too rapid drying of the concrete during setting, and suitable protection against too early use by traffic.

45. [47.] Placing Macadam or Gravel Shoulders. *Note.* If plans provide for gravel or macadam shoulders, specify manner of placing and finishing.

46. [48.] Cleaning Up. *Note.* Provide for removal of all excess material and debris resulting from construction operations, and the final dressing up of shoulders and ditches if such are used.

47. [49.] Preparing Surface for Bituminous Coating. *Note.* Describe the method and the desired thoroughness of cleaning the surface of the concrete before beginning the application of the bituminous surfacing.

48. [50.] Spreading Bituminous Materials. *Note.* Describe the method of applying and spreading bituminous material, temperature of the application, weather conditions under which the work may be done, and the quantity to be used.

49. [51.] Dressing the Surface. *Note.* The bituminous material shall be covered with specified screened gravel or hard crushed stone chips, as *may be desired.*

DISCUSSION

Professor Talbot:—The committee understood that its duties involved merely a statement of those matters which should be included in a form of contract, and not a complete contract. The outline gives the principal items, that in the opinion of the committee, it should include. Most of the provisions given are, I believe, ordinarily given in the specifications. It was thought that until all the committee reports were in, and the method of doing the work decided upon by the Convention, it would not be in order for this committee to make any effort to draw up a complete set of specifications.

Mr. Hewitt:—I want more particularly to confine my remarks to general clauses. It is with those things that the engineers or inspectors crucify the contractors. It is my opinion that there should be incorporated some forms of general clauses, and that the changes made in any kind of work should be reduced to a minimum. These clauses should be fair for both sides.

I believe that the lump sum method of bidding on road work is an unfair proposition. It may be unfair to the municipality, to the county or the state. Some specifications state definitely that the estimates given are only approximate, although they represent the result of calculations, and that the contractor must be responsible for his own data on which to base his bids. Then the different items in these specifications are enumerated as in the following example:

"The undersigned, having carefully examined the plans, profiles and specifications for the improvement known as .... proposes to furnish all materials, all tools, and do all the work necessary for such improvement in accordance with said plans, profiles and specifications, for the following gross prices."

If we now turn to the general clauses, we find the following:

"Incidental work at contractor's expense. All the work to be done by the contractor specified or mentioned in the preceding sections, as well as any minor details of work not specially mentioned in the specifications but obviously necessary for the proper completion of the work, shall be considered as incidental and as being a part of and included in the contract. The contractor will not be entitled to any extra or additional compensation."

In other words the contractor has to put a gold top on the pavement if the engineer wants it. Nor, according to the specifications, is the contractor allowed to charge anything for such work.

The clause providing for extra work is always a bone of contention between the contractor and the engineer and, therefore, it seems to me, a fair specification for such a clause ought to be in the committee's recommendations. I do not think that any engineer is capable of foreseeing, at the time he makes out specifications, all the conditions that may arise in laying out a road several miles long. Many things may change. There may be a lapse of a year or two from the time the specifications are made and the estimate is submitted. When the engineer comes to construct the road, he may want to do it differently than at first contemplated. The contract contains a clause stating that the contractor will not receive pay for any extra work unless he receives written notice. The conditions that make such a step necessary usually require prompt action, so that it is impossible to give written notice to the contractor. In many cases it is necessary to get authority from the supervising board for such extra work.

I believe that general clauses should also provide what percentage should be paid to the contractor and what allowance there shall be for superintend-

ence and tools, and what these percentages shall be based on. It is much easier to keep out of court by writing the proper specifications in the first instance than after the work has been started under improperly written specifications. It is my opinion that the specifications should contain such a set of clauses prepared by an able body of engineers who have considered both sides of the question.

Mr. A. N. Johnson:—To perhaps excuse the specifications that the Illinois State Highway Commission is obliged to place before the contractors, calling for lump sum bids, I would like to state that we do that because in the statute it says that all contracts shall be let on lump sum bids, and it was the wisdom of the legislature alone that decided this point. This, of course, puts the engineer in a quandary, just as Mr. Hewitt has explained. We can lay out no extra work. This I am attempting to dodge in the specifications we are now drawing up and have in preparation, by setting aside an allotment from the money we get, a certain amount for extra work. We will then define extra work in the specifications as being anything beyond what is shown in the plans. It is of course possible to make plans and cross sections in such detail as to show to any contractor or engineer rather definitely what is wanted. Then when we ask for anything beyond what is shown in these lines we will call that extra work. The only way we can provide for this is by pre-arrangement, stating that the extra work shall be done at actual cost. We can then define actual cost so the contractor will know what is meant by it, and so that he will not charge for several jobs that his company is doing in various other parts of the state. In addition to this the contractor shall be allowed a certain percentage above the actual cost.

I think that we all recognize that the fairest sort of practice to the contractor, the engineer, and every one concerned, is the itemized unit price; and I think that where we call for these unit prices it is well for the engineer to state what the prices for each item shall be. I think that the engineer should name as many items and the price of each of them as he thinks will come up for any particular job. The bidder can then name a percentage above or below such prices, for which he will do the work. The contractor's bid may be 90 per cent of the price named, or 102 per cent, and the prices shall have been fixed relatively one to the other. You should not allow the contractor to take advantage of you by making an unbalanced bid, as many of them do who know the local conditions and what will probably be called for in excess of what is first charged. I think that this method of naming unit prices and asking for percentage bids on them is the fairest and best way to get good results. However, under the statute that we have in Illinois, we are unable to do that.

Mr. Larned:—I was interested to find that provision had been made for a decision by the engineer not acceptable to the contractor. Although I do not know what is proposed as the recourse, I can cite the practice in certain sections of the country where we have a so-called uniform contract which calls for arbitration; and the way the arbitration board shall be constituted is usually stated. This secures without question the consideration of men who ordinarily are able to settle the matter with justice and fairness to both sides. The contractor does not want litigation, nor does the engineer, and it seldom happens that both are entirely unbiased in settling the question between themselves. I think it would be well to provide some provision for *arbitration.*

Mr. Charles W. Baker:—I think that this report gives us something to think over very carefully. The committee has given us forty-nine different heads under which a specification could be drafted. Under some of these heads we have had presented whole committee reports. If we are going to attempt to define in every last particular how the contractor shall proceed from the time the contract is let until the job is finished, we will have not merely a specification but a very large treatise. This is a condition that contractors and engineers ought to consider very seriously. Our specifications have been growing and growing all the time. I recently had to go over the specifications for a road for which I was partially responsible, and I was amazed at the length and amount of particulars that were embodied in that specification. It has almost come to the point where we shall have to pay the contractor something to read the specifications. Of course this is not always so, and I think, as a matter of fact, in many of the jobs that are let, the simple specifications, comparatively brief, cover pretty much everything that is required. An attempt to define everything that may possibly come up is, in my mind, attempting the impossible. Even if this is attempted it would still be necessary, as has been pointed out by some of the previous speakers, to make extra provision for some of the things that cannot be foreseen.

There is one point that I want to strongly emphasize. Although the committee has made a heading for a guarantee, it has taken no stand on how that guarantee shall be provided. I wish to go on record as saying that guarantees on paving contracts are against the interests of the public. It is unjust to ask the contractor to do a certain job of paving when the engineer says exactly how he shall do it, what materials he shall use, how they shall be placed, and then make him responsible for what happens to that work. It is unjust to the contractor and unjust to the public. For instance, here is a specification which requires the contractor to guarantee a certain pavement and keep it in repair for five years. This means that during that time the contractor's bond, on which he must continue to pay some bonding company some sort of commission, will have to continue. Of course the contractor has no recourse but to make allowances for this, so that the public ultimately pays for it.

Mr. Hewitt:—In most states it is illegal to make a property owner maintain a pavement after asking him to pay for constructing it. I think in most cases it is enough to ask the property owner to pay his assessment, without requiring him to pay for guaranteeing it for five years.

Professor Talbot:—I quite agree with the views expressed regarding guarantees. It is much better to apply a small part of the amount which will be required for a guarantee, in getting better engineering, better inspection service, and better relations with the contractor. I think the committee sympathizes with Mr. Hewitt in his reference to certain clauses in contracts, putting the contractor so thoroughly in the hands of the engineer. I do not believe that anything of that kind was intended in the wording as given.

In regard to extra work, the provision is here made that changes of plans may be made when necessary, according to a specified form of procedure; but if productive of increased cost, allowance for such increase shall be made. This increased amount for the change to be agreed upon in writing when the work is started. Deductions may be made in like manner. Changes in plans so made shall not invalidate the contract. It seems to me that it would be wise to put in some provision, whenever possible, as to the ways of getting at the value for work to be changed, or extra work to be done. The com-

mittee does not feel, of course, that these proposed forms are in final shape. In fact, it seems to me that if a committee could be appointed by this Conference, or if some means could be provided by this Conference whereby a uniform form of contract could be written, after careful study and consideration by those on both sides who have been interested in road work, that it would be of great advantage to road construction, and would be one of the best things that could be accomplished by this Conference.

Mr. Larned:—I would like to suggest consideration of a clause that is found in many city contracts which requires a reservation of 5 or 10 per cent. This requires a contractor to use a large amount of capital, or else to borrow. I have often found instances where an unnecessary amount is held back. Ordinarily the work is perfectly safeguarded by bond, and it is not often that we have to take advantage of that. The amount of money held back from the contractor is often a real handicap to him. I think that it would be wise to make a provision that certain payments from the reserve fund be made when the work reaches a certain point of completion.

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Auditorium Hotel, Chicago,

February 12-13-14,

1914

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Standard Specifications for Concrete Roads and Pavements of the

American Concrete Institute

1914

One Course Concrete Highway

I. MATERIALS

1. CEMENT: The cement shall meet the requirements of the Standard Specifications for Portland Cement, adopted by the American Society for Testing Materials, August 16, 1909, with all subsequent amendments and additions thereto adopted by said society, and adopted by this institute. (Standard No. 1.)

When the cement is not inspected at the place of manufacture, it shall be stored a sufficient length of time to permit of inspecting and testing. The engineer shall be notified of the receipt of each shipment of cement.

2. FINE AGGREGATE: Fine aggregate shall consist of sand or screenings from clean, hard, durable crushed rock or gravel consisting of quartzite grains or other equally hard material graded from fine to coarse with the coarse particles predominating and passing, when dry, a screen having one-fourth (¼) inch openings. It shall be clean, hard, free from dust, loam, vegetable, or other deleterious matter. Not more than twenty (20) per cent shall pass a sieve having fifty (50) meshes per linear inch, and not more than five (5) per cent shall pass a sieve having one hundred (100) meshes per linear inch.

Fine aggregate containing more than three (3) per cent of clay or loam shall be washed before using.

Fine aggregate shall be of such quality that the mortar composed of one (1) part Portland cement and three (3) parts fine aggregate by weight, when made into briquettes, shall show a tensile strength at least equal to the strength of 1:3 mortar of the same consistency, made with the same cement and Standard Ottawa sand. In no case shall fine aggregate containing frost or lumps of frozen material be used.

3. COARSE AGGREGATE: Coarse aggregate shall consist of clean, hard, durabie crushed rock or gravel, graded in size, free from dust, loam, vegetable or other deleterious matter and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a one and one-half (1½) inch round opening and be retained on a screen having one-quarter (¼) inch openings. In no case shall coarse aggregate containing frost or lumps of frozen material be used.

4. NATURAL MIXED AGGREGATE: Natural mixed aggregate shall not be used as it comes from deposits but shall be screened and used as specified.

5. WATER: Water shall be clean, free from oil, acid, alkali or vegetable matter.

6. REINFORCEMENT: Concrete pavements twenty (20) feet or more in width shall be reinforced with metal fabric. All reinforcement shall

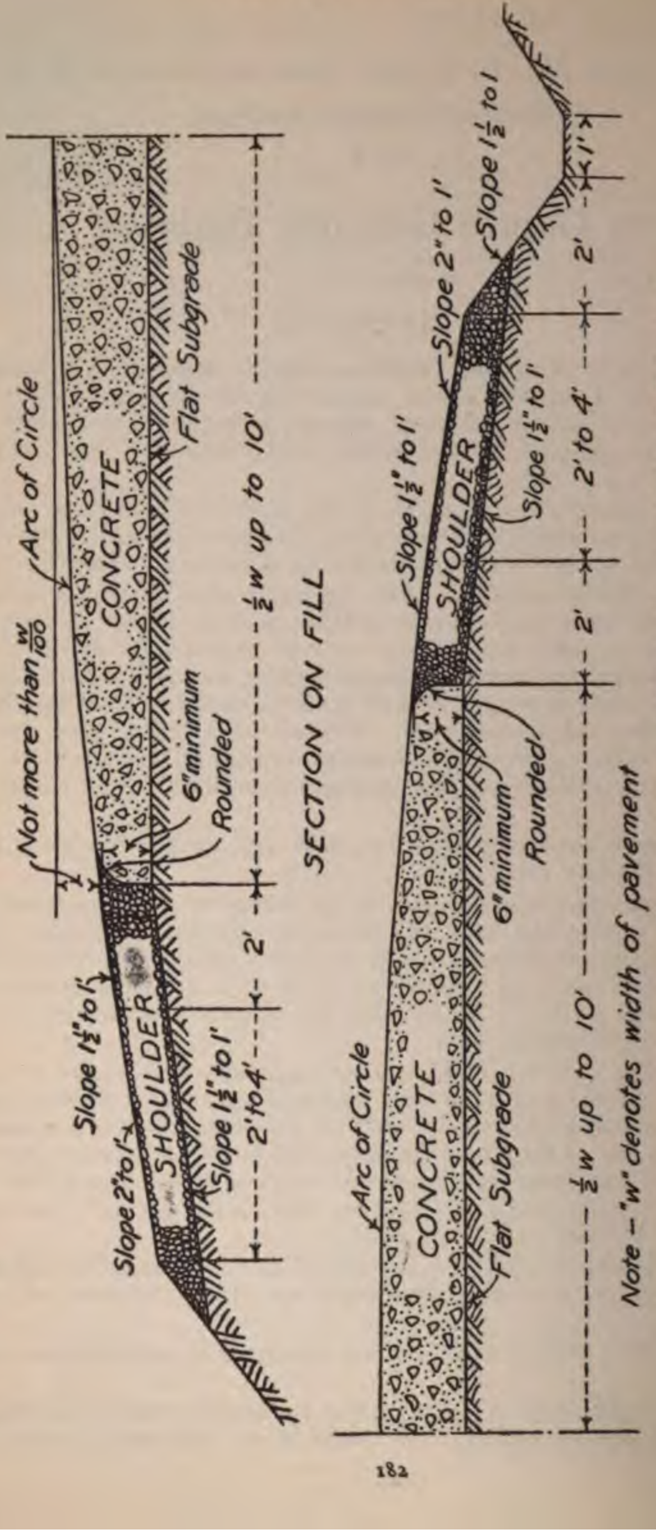

FIG. 12. ONE COURSE CONCRETE HIGHWAY

be free from excessive rust, scale, paint or coatings of any character which will tend to destroy the bond. All reinforcement shall develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180° around one diameter and straighten without fracture.

7. JOINT FILLER: Joint Filler shall consist of prepared felt or similar material of approved quality having a thickness of not less than one-eighth (1/8) nor more than one-quarter (1/4) inch.

8. JOINT PROTECTION PLATES: Soft steel plates for the protection of the edges of the concrete at transverse joints shall be not less than two and one-half (2½) inches in depth and not less than one-eighth (1/8) at any point nor more than one-quarter (1/4) inch average thickness. The plates shall be of such form as to provide for rigid anchorage to the concrete. The type and method of installation of joint protection plates shall be approved by the engineer.

9. SHOULDERS: Materials for the construction of shoulders shall be approved by the engineer.

II. GRADING

10. DEFINED: The term "grading" shall include all cuts, fills, ditches, borrow pits, approaches and all earth moving for whatever purpose where such work is an essential part of or necessary to the prosecution of the contract. When, to bring the surface to grade, a fill of one (1) foot or less is required, the area shall be thoroughly grubbed. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be removed and the space refilled with suitable material.

11. ENGINEER'S STAKES: Stakes will be set by the engineer for the center line side of slopes, finished grade and other necessary points properly marked for the cut or fill.

12. EXCESS MATERIAL: Excess material shall be disposed of as directed by the engineer, the free haul not to exceed.................. feet.

13. OVER-HAUL: Materials hauled a greater distance than the free haul from the place of excavation shall be paid for at the rate of............. cents per cubic yard for each additional..................feet.

14. FILLS: Embankments shall be formed of earth or other approved materials and shall be constructed in successive layers, the first of which shall extend entirely across from the toe of the slope on one side to the toe of the slope on the other side, and successive layers shall extend entirely across the embankments from slope to slope. Each layer, which shall not exceed one (1) foot in depth, shall be thoroughly rolled with a roller weighing not less than five (5) tons nor more than ten (10) tons before the succeeding layer is placed. The roller shall pass over the entire area of the fill at least twice.

The sides of the embankment shall be kept lower than the center during all stages of the work and the surface maintained in condition for adequate drainage. The use of muck, quicksand, soft clay or spongy material which will not consolidate under the roller is prohibited.

When the material excavated from the cuts is not sufficient to make the fills shown on the plans, the contractor shall furnish the necessary extra material to bring the fills to the proper width and grade. When the earth work is completed, the cross section of the road shall conform to the cross sectional drawings and profile shown in Figure 12, page 182.

15. SLOPES: All slopes must be properly dressed to lines given by the engineer.

16. FINISHED GRADE: When the grade line is approached the final grade stakes will be set, for which sufficient notice must be given to the engineer.

Note: (In excavating cuts, it is considered advisable, when the line of the sub-grade is approached, to compact the remaining material by rolling. The depth of material left in the cut to be compressed to the finished grade by rolling will depend upon the character of the material.)

III. DRAINAGE

17. DRAINAGE: The contractor shall construct such drainage ditches as will insure perfect sub- and surface-drainage during construction and such work shall be completed to the satisfaction of the engineer, prior to the preparation of the roadbed, as herein specified.

Tile drains shall be placed as shown in the drawings attached hereto. Tile to be laid in the trench at least........................(........) inches wide and .... (.........) feet deep below the established grade of the finished pavement. Such trench shall be back filled with crushed stone or pit run gravel, with sand removed, which after light tamping shall be.......................(........) inches in depth.

Open ditches must be constructed along the concrete road as shown in Figure 12, page 182, the dimensions, side slopes and grade of said ditches being as shown on the cross section drawings and profile.

At the time of the acceptance of the road, the ditches must be in perfect condition with clean slopes and bottom, containing no obstructions to the flow of water.

IV. SUB-GRADE

18. CONSTRUCTION: The bottom of the excavation or the top of the fill when completed shall be known as the sub-grade and shall be at all places true to the elevation as shown on the plans attached hereto.

The roadway shall be graded to the proper sub-grade to permit of the specified thickness of paving materials being laid to bring the finished surface of the pavement to the lines and grades as shown on the plans.

The sub-grade shall be brought to a firm, unyielding surface by rolling the entire area with a self-propelled roller weighing not less than ten (10) tons, and all portions of the surface of the sub-grade which are inaccessible to the roller shall be thoroughly tamped with a hand tamp weighing not less than fifty (50) pounds, the face of which shall not exceed one hundred (100) square inches in area. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be entirely removed and the space refilled with suitable material.

Where considered necessary or of assistance in producing a compact, solid surface, the sub-grade before being rolled shall be well sprinkled with water.

When the concrete pavement is to be constructed over an old roadbed composed of gravel or macadam, and the concrete is to be wider than the old gravel or macadam road, the latter shall be entirely loosened and the material spread for the full width of the roadbed and rolled. All interstices

shall be filled with fine material, and rolled to make a dense, tight surface of the roadbed.

19. ACCEPTANCE: No concrete shall be deposited upon the sub-grade until it is checked and accepted by the engineer.

20. COMPLETION: Upon the sub-grade thus formed shall be laid the concrete pavement as shown in Figure 12, page 182.

V. FORMS

21. MATERIALS: The forms shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the thickness of the pavement at the edges. Wooden forms shall be of not less than two (2) inch stock, and shall be capped with two (2) inch angle iron.

22. SETTING: The forms shall be well staked or otherwise held to the established line and grades, and the upper edges shall conform to the established grade of the road.

23. TREATMENT: All mortar and dirt shall be removed from the forms that have previously been used.

VI. PAVEMENT SECTION

24. WIDTH, THICKNESS OF CONCRETE AND CROWN: The concrete pavement shall be..............................feet wide, ...(........) inches in depth at center, and ....(........) inches in depth at the sides. The finished surface shall conform to the arc of a circle, as shown in Figure 12, page 182.

> Note: (Crown shall be not more than one-one-hundredth (1/100) of the width. The thickness of the concrete at the edges shall not be less than six (6) inches.)

VII. JOINTS

25. WIDTH AND LOCATION: Transverse joints shall be not less than one-quarter (¼) inch nor more than three-eighths (⅜) inch in width and shall be placed across the pavement perpendicular to the center line, not more than 35 feet apart. When a curb is specified or where pavement abuts a building a joint not less than one-quarter (¼) inch wide shall be placed between it and the pavement. All joints shall extend through the entire thickness of the pavement and shall be perpendicular to its surface.

26. PROTECTION OF JOINTS: The concrete at transverse joints shall be protected with soft steel joint protection plates which shall be rigidly anchored to the concrete. The installation of the metal protection plates shall meet with the approval of the engineer. The surface edges of the metal plates shall conform to the finished surface of the concrete, as shown in Figure 12.

All joints over one-quarter (¼) inch high or one-half (½) inch low shall be removed.

27. JOINT FILLER: All joints shall be formed by inserting during construction and leaving in place the required thickness of joint filler which shall extend through the entire thickness of the pavement.

VIII. MEASURING MATERIALS AND MIXING CONCRETE

28. MEASURING MATERIALS: The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A bag of Portland cement (94 lbs. net) shall be considered one (1) cubic foot.

29. MIXING: The materials shall be mixed to the desired consistency in a batch mixer of approved type, and mixing shall continue for at least forty-five (45) seconds after all materials are in the drum. The drum shall be completely emptied before mixing successive batches. The drum of the mixer used shall revolve at a speed not less than the minimum nor more than the maximum number of revolutions shown in the following table:

Rated capacity cu. ft. unmixed material.	Capacity bags of cement 1:2:3 mix.	Revolutions per minute of drum. Min.	Max.
7 to 11	1	15	21
12 to 17	2	12	20
18 to 23	3	12	20
24 to 29	4	11	17
30 to 33	5	10	15

30. RETEMPERING: Retempering of mortar or concrete which has partially hardened, that is, mixing with additional materials or water, shall not be permitted.

31. PROPORTIONS: The concrete shall be mixed in the proportions of one (1) bag of Portland cement to not more than two (2) cubic feet of fine aggregate and not more than three (3) cubic feet of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half (½) the volume of the coarse aggregate.

A cubic yard of concrete in place between neat lines shall contain not less than one and seven-tenths (1.7) barrels of cement.

The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete between successive transverse joints, as determined by actual count of the number of bags of cement used in each section. If the amount of cement used in any three adjacent sections (between transverse joints) is less by two (2) per cent, or if the amount of cement used in any one section is less by five (5) per cent, than the amount hereinbefore specified, the contractor agrees to remove all such sections and to rebuild the same according to these specifications at his expense.

32. CONSISTENCY: The materials shall be mixed with sufficient water to produce a concrete which when deposited will settle to a flattened mass, but shall not be so wet as to cause a separation of the mortar from the coarse aggregate in handling.

IX. REINFORCING

33. REINFORCING: Concrete pavements twenty (20) feet or more in width shall be reinforced. The cross-sectional area of the reinforcing metal running parallel to the center line of the pavement shall amount to at least 0.038 square inch per foot of pavement width and the cross-sectional area of reinforcing metal, which is perpendicular to the center line of the pavement, shall amount to at least 0.049 square inch per foot of pavement length.

Reinforcing metal shall not be placed less than two (2) inches from the finished surface of the pavement and otherwise shall be placed as shown on

the drawings. The reinforcing metal shall extend to within two (2) inches of all joints, but shall not cross them. Adjacent widths of fabric shall be lapped not less than four (4) inches.

X. PLACING CONCRETE

34. PLACING CONCRETE: Immediately prior to placing the concrete, the sub-grade shall be brought to an even surface. The surface of the sub-grade shall be thoroughly wet when the concrete is placed.

After mixing, the concrete shall be deposited rapidly in successive batches upon the sub-grade prepared as hereinbefore specified. The concrete shall be deposited to the required depth and for the entire width of the pavement, in a continuous operation, between transverse joints without the use of intermediate forms or bulkheads.

In case of a breakdown concrete shall be mixed by hand to complete the section or an intermediate transverse joint placed as hereinbefore specified at the point of stopping work. Any concrete in excess of that needed to complete a section at the stopping of work shall not be used in the work.

35. FINISHING: The surface of the concrete shall be struck off by means of a template or strike board which shall be moved with a combined longitudinal and cross-wise motion. When the strike board is within three (3) feet of a transverse joint it shall be lifted to the joint and the pavement struck by moving the strike board away from the joint; any excess concrete shall be removed. Concrete adjoining the metal protection plates at transverse joints shall be dense in character and any holes left by removing any device used in installing the metal protection plates shall be immediately filled with concrete.

After being brought to the established grade with the template or strike board, the concrete shall be finished from a suitable bridge, no part of which shall come in contact with the concrete. The concrete shall be finished with a wood float in a manner to thoroughly compact it and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than one-quarter (¼) inch from the true shape.

The edges of the pavement shall be rounded as shown on the cross sectional drawings attached hereto.

XI. PROTECTION

36. CURING AND PROTECTION: Excepting as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than two (2) inches of earth or other material which will afford equally good protection, which cover shall be kept moist for at least ten (10) days. When deemed necessary or advisable by the engineer, freshly laid concrete shall be protected by a canvas covering until the earth covering can be placed.

Under the most favorable conditions for hardening in hot weather the pavement shall be closed to traffic for at least fourteen (14) days, and in cool weather for an additional time, to be determined by the engineer.

If at the time the pavement is laid, or during the period of curing, the temperature during the daytime drops below 50 degrees Fahrenheit, sprinkling and covering of the pavement shall be omitted at the direction of the engineer.

The contractor [illegible]rect and maintain suitable barriers to protect the concrete from traffic [illegible] any part of the pavement damaged from traffic or other causes, occurring prior to its official acceptance, shall be repaired or replaced by the contractor at his expense, in a manner satisfactory to the engineer. Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

37. TEMPERATURE BELOW 35 DEGREES FAHRENHEIT: Concrete shall not be mixed or deposited when the temperature is below freezing.

If at any time during the progress of the work the temperature is, or in the opinion of the engineer will within twenty-four (24) hours drop to 35 degrees Fahrenheit, the water and aggregates shall be heated, and precautions taken to protect the work from freezing for at least ten (10) days. In no case shall concrete be deposited upon a frozen sub-grade.

XII. SHOULDERS

38. CONSTRUCTION: When shoulders are required, they shall be built upon the properly prepared sub-grade, as shown on the cross sectional drawing, Figure 12, page 182. The work shall be done to the entire satisfaction of the engineer.

Committee on Standard Specifications for Concrete Roads and Pavements

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JAMES R. MARKER,
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Standard Specifications for Concrete Roads and Pavements of the

American Concrete Institute

1914

One Course Concrete Street Pavement

I. MATERIALS

1. CEMENT: The cement shall meet the requirements of the Standard Specifications for Portland Cement, adopted by the American Society for Testing Materials, August 16, 1909, with all subsequent amendments and additions thereto adopted by said Society, and adopted by this institute. (Standard No. 1.)

When the cement is not inspected at the place of manufacture it shall be stored a sufficient length of time to permit of inspecting and testing. The engineer shall be notified of the receipt of each shipment of cement.

2. FINE AGGREGATE: Fine aggregate shall consist of sand or screenings from clean, hard, durable crushed rock or gravel consisting of quartzite grains or other equally hard material graded from fine to coarse, with the coarse particles predominating and passing, when dry, a screen having one-quarter (¼) inch openings. It shall be clean, hard, free from dust, loam, vegetable, or other deleterious matter. Not more than twenty (20) per cent shall pass a sieve having fifty (50) meshes per linear inch, and not more than five (5) per cent shall pass a sieve having one hundred (100) meshes per linear inch.

Fine aggregate containing more than three (3) per cent of clay or loam shall be washed before using.

Fine aggregate shall be of such quality that the mortar composed of one (1) part Portland cement and three (3) parts fine aggregate by weight, when made into briquettes, shall show a tensile strength at least equal to the strength of 1:3 mortar of the same consistency made with the same cement and Standard Ottawa sand. In no case shall fine aggregate containing frost or lumps of frozen material be used.

3. COARSE AGGREGATE: Coarse aggregate shall consist of clean, hard, durable crushed rock or gravel, graded in size, free from dust, loam, vegetable or other deleterious matter, and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a one and one-half (1½) inch round opening and be retained on a screen having one-quarter (¼) inch openings. In no case shall coarse aggregate containing frost or lumps of frozen material be used.

4. NATURAL MIXED AGGREGATE: Natural mixed aggregate shall not be used as it comes from deposits, but shall be screened and used as specified.

5. WATER: Water shall be clean, free from oil, acid, alkali, or vegetable matter.

6. REINFORCEMENT: Concrete pavements twenty (20) feet or more in width shall be reinforced with metal fabric. All reinforcement shall

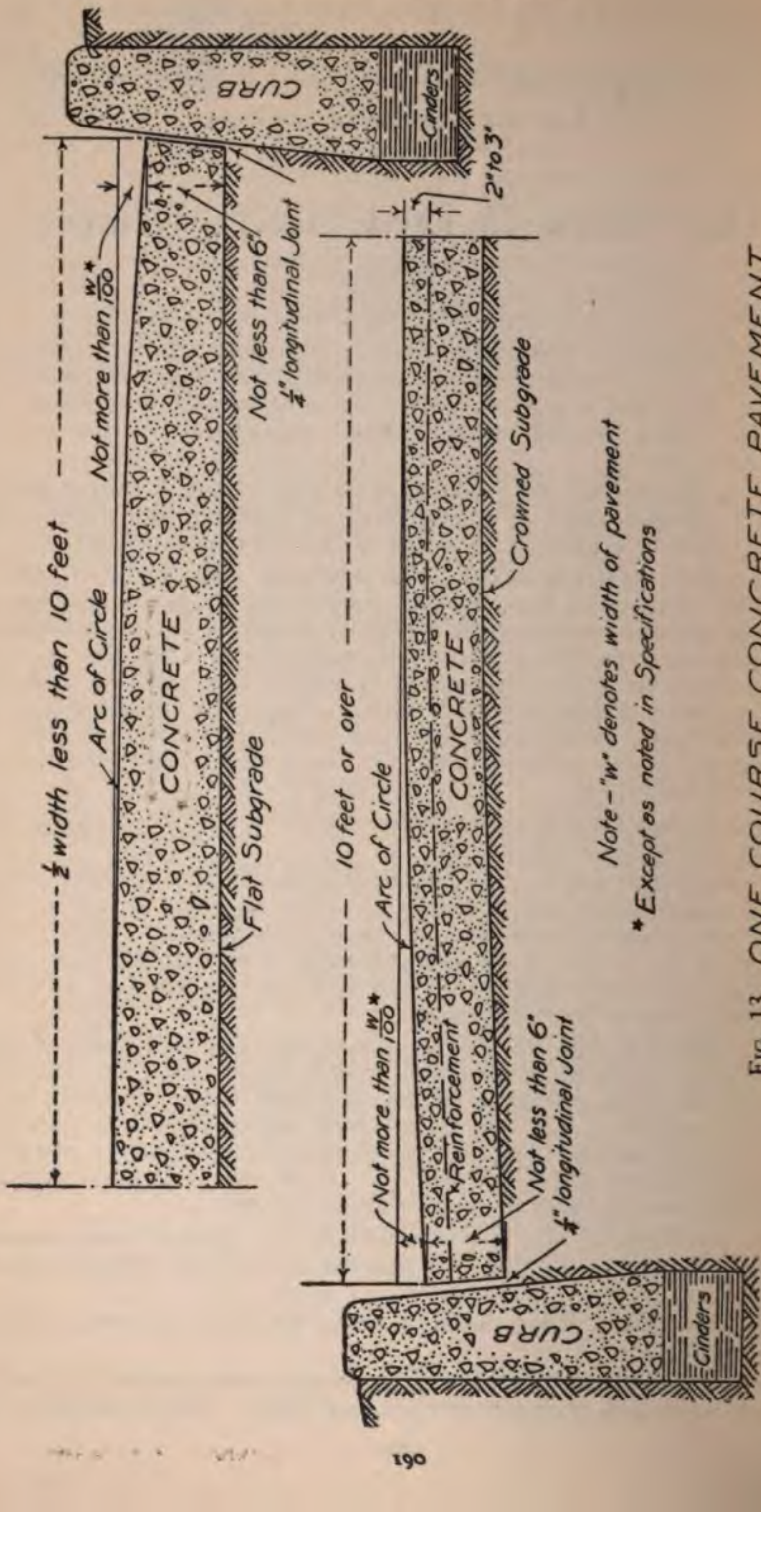

FIG. 13. ONE COURSE CONCRETE PAVEMENT

be free from excessive rust, scale, paint, or coatings of any character which will tend to destroy the bond. All reinforcement shall develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180° around one diameter and straighten without fracture.

7. JOINT FILLER: Joint Filler shall consist of prepared felt or similar material of approved quality having a thickness of not less than one-eighth (1/8) nor more than one-quarter (1/4) inch.

8. JOINT PROTECTION PLATES: Soft steel plates for the protection of the edges of the concrete at transverse joints shall be not less than two and one-half (2 1/2) inches in depth and not less than one-eighth (1/8) at any point nor more than one-quarter (1/4) inch average thickness. The plates shall be of such form as to provide for rigid anchorage to the concrete. The type and method of installation of joint protection plates shall be approved by the engineer.

9. SHOULDERS: Materials for the construction of shoulders shall be approved by the engineer.

II. GRADING

10. DEFINED: The term "grading" shall include all cuts, fills, approaches and all earth moving for whatever purpose where such work is an essential part of or necessary to the prosecution of the contract. When, to bring the surface to grade, a fill of one (1) foot or less is required, the area shall be thoroughly grubbed. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be removed and the space refilled with suitable material.

11. ENGINEER'S STAKES: Stakes will be set by the engineer for the center line, side of slopes, finished grade and other necessary points properly marked for the cut or fill.

12. EXCESS MATERIAL: Excess material shall be disposed of as directed by the engineer, the free haul not to exceed.................. feet.

13. OVER-HAUL: Materials hauled a greater distance than the free haul from the place of excavation shall be paid for at the rate of ....cents per cubic yard for each additional..............feet.

14. FILLS: Embankments shall be formed of earth or other approved materials and shall be constructed in successive layers, the first of which shall extend entirely across from the toe of the slope on one side to the toe of the slope on the other side, and successive layers shall extend entirely across the embankments from slope to slope. Each layer, which shall not exceed one (1) foot in depth, shall be thoroughly rolled with a roller weighing not less than five (5) tons nor more than ten (10) tons before the succeeding layer is placed. The roller shall pass over the entire area of the fill at least twice.

The sides of the embankment shall be kept lower than the center during all stages of the work, and the surface maintained in condition for adequate drainage. The use of muck, quicksand, soft clay or spongy material which will not consolidate under the roller, is prohibited.

When the material excavated from the cuts is not sufficient to make the fills shown on the plans, the contractor shall furnish the necessary extra material to bring the fills to the proper width and grade. When the earth work is completed the cross section of the road shall conform to the cross sectional drawing and profile, Figure 13, page 190.

15. SLOPES: All slopes must be properly dressed to lines given by the engineer.

16. FINISHED GRADE: When the grade line is approached, the final grade stakes will be set, for which sufficient notice must be given to the engineer.

Note: (In excavating cuts it is considered advisable, when the line of the sub-grade is approached, to compact the remaining material by rolling. The depth of material left in the cut to be compressed to the finished grade by rolling will depend upon the character of the material.)

III. DRAINAGE

17. DRAINAGE: The contractor shall construct tile or other drains as shown in the drawings attached hereto. Tile to be laid in the trench at least.............. (.......) inches wide, and............. (.......) feet deep below the top of the adjacent curb. Such trench shall be back filled with crushed stone or pit run gravel with sand removed, which after light tamping shall be................(......) inches in depth.

18. CATCH BASINS: All catch basin and manhole tops and all covers of openings of any kind shall be readjusted to the grade by the contractor at his expense.

IV. SUB-GRADE

19. CONSTRUCTION: The bottom of the excavation or top of the fill, when completed, shall be known as the sub-grade, and shall be at all places true to the elevation as shown on the plans attached hereto.

The street shall be graded from curb to curb to the proper sub-grade to permit of the specified thickness of paving materials being laid to bring the finished surface of the pavement to the lines and grades as shown on the plans.

The sub-grade shall be brought to a firm, unyielding surface by rolling the entire area with a self-propelled roller weighing not less than ten (10) tons, and all portions of the surface of the sub-grade which are inaccessible to the roller shall be thoroughly tamped with a hand tamp weighing not less than fifty (50) pounds, the face of which shall not exceed one hundred (100) square inches in area. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be entirely removed and the space refilled with suitable material.

Where considered necessary or of assistance in producing a compact solid surface the sub-grade, before being rolled, shall be well sprinkled with water.

When the concrete pavement is to be constructed over an old roadbed composed of gravel or macadam, and the concrete is to be wider than the old gravel or macadam road, the latter shall be entirely loosened and the material spread for the full width of the roadbed and rolled. All interstices shall be filled with fine material, and rolled to make a dense, tight surface of the roadbed.

20. ACCEPTANCE: No concrete shall be deposited upon the sub-grade until it is checked and accepted by the engineer.

21. COMPLETION: Upon the sub-grade thus formed shall be laid the concrete pavement as shown in Figure 13, page 190.

V. FORMS

22. MATERIALS: The forms shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the

thickness of the pavement at the edges. Wooden forms shall be of not less than two (2) inch stock and shall be capped with two (2) inch angle iron.

23. SETTING: The forms when required shall be well staked or otherwise held to the established line and grades and the upper edges shall conform to the established grade of the street.

24. TREATMENT: All mortar and dirt shall be removed from the forms that have previously been used.

VI. PAVEMENT SECTION

25. WIDTH, THICKNESS OF CONCRETE AND CROWN: The concrete pavement shall be................feet wide................ (......) inches in depth at center and ....(......) inches in depth at the sides. The finished surface shall conform to the arc of a circle as shown in Figure 13, page 190.

> Note: (The thickness of the concrete at the edges shall not be less than six (6) inches. When pavements twenty (20) feet or less in width are to be built on approximately level ground and a flat sub-grade is to be used, sufficient fall for drainage at the sides of the pavement along the curb shall be provided by giving the roadbed the same grade as that proposed for the gutter. The crown of all pavements shall not be more than one-one-hundredth (1/100) of the width except when deemed advisable by the engineer, the crown of a pavement built on a crowned sub-grade may be increased to one-fiftieth (1/50) of the width to provide sufficient fall for drainage along the sides of the pavement at the curb.)

VII. JOINTS

26. WIDTH AND LOCATION: Transverse joints shall be not less than one-quarter (¼) inch nor more than three-eighths (⅜) inch in width, and shall be placed across the pavement perpendicular to the center line, not more than thirty-five (35) feet apart. A longitudinal joint not less than one-quarter (¼) inch wide shall be constructed between the curb and the pavement. All joints shall extend through the entire thickness of the pavement, and shall be perpendicular to its surface.

27. PROTECTION OF JOINTS: The concrete at transverse joints shall be protected with soft steel joint protection plates which shall be rigidly anchored to the concrete. The type and installation of the metal protection plates shall meet with the approval of the engineer. The surface edges of the metal plates shall conform to the finished surface of the concrete, as shown in Figure 13, page 190.

All joints over one-quarter (¼) inch high or one-half (½) inch low shall be removed.

28. JOINT FILLER: All joints shall be formed by inserting during construction and leaving in place the required thickness of joint filler which shall extend through the entire thickness of the pavement.

VIII. MEASURING MATERIALS AND MIXING CONCRETE

29. MEASURING MATERIALS: The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A bag of Portland cement (94 pounds net) shall be considered one (1) cubic foot.

30. MIXING: The materials shall be mixed to the desired consistency in a batch mixer of approved type, and mixing shall continue for at least forty-five (45) seconds after all materials are in the drum. The drum shall be completely emptied before mixing successive batches. The drum of the mixer used shall revolve at a speed not less than the minimum nor more than the maximum number of revolutions shown in the following table:

Rated capacity cu. ft. unmixed material.	Capacity bags of cement 1:2:3 mix.	Revolutions per minute of drum. Min.	Max.
7 to 11	1	15	21
12 to 17	2	12	20
18 to 23	3	12	20
24 to 29	4	11	17
30 to 33	5	10	15

31. RETEMPERING: Retempering of mortar or concrete which has partially hardened, that is, mixing with additional materials or water, shall not be permitted.

32. PROPORTIONS: The concrete shall be mixed in the proportions of one (1) bag of Portland cement to not more than two (2) cubic feet of fine aggregate and not more than three (3) cubic feet of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half (½) the volume of the coarse aggregate.

A cubic yard of concrete in place between neat lines shall contain not less than one and seven-tenths (1.7) barrels of cement.

The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete, between successive transverse joints, as determined by actual count of the number of bags of cement used in each section. If the amount of cement used in any three adjacent sections (between transverse joints) is less by two (2) per cent, or if the amount of cement used in any one section is less by five (5) per cent than the amount hereinbefore specified, the contractor agrees to remove all such sections and to rebuild the same according to these specifications, at his expense.

33. CONSISTENCY: The materials shall be mixed with sufficient water to produce a concrete which when deposited will settle to a flattened mass, but shall not be so wet as to cause a separation of the mortar from the coarse aggregate in handling.

IX. REINFORCING

34. REINFORCING: Concrete pavements twenty (20) feet or more in width shall be reinforced. The cross-sectional area of the reinforcing metal running parallel to the center line of the pavement shall amount to at least 0.038 square inch per foot of pavement width and the cross-sectional area of reinforcing metal, which is perpendicular to the center line of the pavement, shall amount to at least 0.049 square inch per foot of pavement length.

Reinforcing metal shall not be placed less than two (2) inches from the finished surface of the pavement and otherwise shall be placed as shown on the drawings. The reinforcing metal shall extend to within two (2) inches of all joints, but shall not cross them. Adjacent widths of fabric shall be lapped not less than four (4) inches.

X. PLACING CONCRETE

35. PLACING CONCRETE: Immediately prior to placing the concrete, the sub-grade shall be brought to an even surface. The surface of the sub-grade shall be thoroughly wet when the concrete is placed.

After mixing, the concrete shall be deposited rapidly in successive batches upon the sub-grade, prepared as hereinbefore specified. The concrete shall be deposited to the required depth and for the entire width of the pavement, in a continuous operation, between transverse joints, without the use of intermediate forms or bulkheads.

In case of a breakdown, concrete shall be mixed by hand to complete the section or an intermediate transverse joint placed as hereinbefore specified at the point of stopping work. Any concrete in excess of that needed to complete a section at the stopping of work shall not be used in the work.

36. FINISHING: The surface of the concrete shall be struck off by means of a template or strike board, which shall be moved longitudinally or crosswise of the pavement. Concrete adjoining the metal protection plates at transverse joints shall be dense in character, and any holes left by removing any device used in installing the metal protection plates shall be immediately filled with concrete.

After being brought to the established grade with the template or strike board, the concrete shall be finished from a suitable bridge, no part of which shall come in contact with the concrete. The concrete shall be finished with a wood float in a manner to thoroughly compact it and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than one-quarter (¼) inch from the true shape.

XI. PROTECTION

37. CURING AND PROTECTION: Excepting as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than two (2) inches of earth or other material which will afford equally good protection, which cover shall be kept moist for at least ten (10) days. When deemed necessary or advisable by the engineer, freshly laid concrete shall be protected by a canvas covering until the earth covering can be placed.

If at the time the pavement is laid, or during the period of curing, the temperature during the daytime drops below 50 degrees Fahrenheit, sprinkling and covering of the pavement shall be omitted at the direction of the engineer.

Under the most favorable conditions for hardening, in hot weather, the pavement shall be closed to traffic for at least fourteen (14) days, and in cool weather for an additional time, to be determined by the engineer.

The contractor shall erect and maintain suitable barriers to protect the concrete from traffic, and any part of the pavement damaged from traffic or other causes occurring prior to its official acceptance, shall be repaired or replaced by the contractor at his expense in a manner satisfactory to the engineer.

Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

38. TEMPERATURE BELOW 35 DEGREES FAHRENHEIT: Concrete shall not be mixed or deposited when the temperature is below freezing.

If at any time during the progress of the work the temperature is, or in the opinion of the engineer will within twenty-four (24) hours drop to 35 degrees Fahrenheit, the water and aggregates shall be heated and precautions taken to protect the work from freezing for at least ten (10) days. In no case shall concrete be deposited upon a frozen sub-grade.

XII. SHOULDERS

39. CONSTRUCTION: Where shoulders are required they shall be built upon the properly prepared sub-grade, as shown on the profile and cross-sectional drawing, Figure 12, page 182. The work shall be done to the entire satisfaction of the engineer.

Committee on Standard Specifications for Concrete Roads and Pavements

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Standard Specifications for Concrete Roads and Pavements of the

American Concrete Institute

1914

Two Course Concrete Street Pavement

I. MATERIALS

1. CEMENT: The cement shall meet the requirements of the Standard Specifications for Portland Cement, adopted by the American Society for Testing Materials, August 16, 1909, with all subsequent amendments and additions thereto, adopted by said society, and adopted by this institute. (Standard No. 1.)

When the cement is not inspected at the place of manufacture it shall be stored a sufficient length of time to permit of inspecting and testing. The engineer shall be notified of the receipt of each shipment of cement.

2. FINE AGGREGATE: Fine aggregate shall consist of sand or screenings from clean, hard, durable crushed rock or gravel consisting of quartzite grains or other equally hard material graded from fine to coarse, with the coarse particles predominating and passing, when dry, a screen having one-quarter (¼) inch openings. It shall be clean, hard, free from dust, loam, vegetable, or other deleterious matter. Not more than twenty (20) per cent shall pass a sieve having fifty (50) meshes per linear inch, and not more than five (5) per cent shall pass a sieve having one hundred (100) meshes per linear inch.

Fine aggregate containing more than three (3) per cent of clay or loam shall be washed before using.

Fine aggregate shall be of such quality that the mortar composed of one (1) part Portland cement and three (3) parts fine aggregate by weight, when made into briquettes, shall show a tensile strength at least equal to the strength of 1:3 mortar of the same consistency made with the same cement and Standard Ottawa sand. In no case shall fine aggregate containing frost or lumps of frozen material be used.

3. COARSE AGGREGATE: Coarse aggregate shall consist of clean, hard, durable crushed rock or gravel, graded in size, free from dust, loam, vegetable or other deleterious matter and shall contain no soft, flat or elongated particles. The size of the coarse aggregate shall be such as to pass a one and one-half (1½) inch round opening and be retained on a screen having one-quarter (¼) inch openings. In no case shall coarse aggregate containing frost or lumps of frozen material be used.

4. AGGREGATE FOR WEARING COURSE: The aggregate for the wearing course shall consist of a mixture of two (2) parts of the materials specified under "Fine Aggregate," and three (3) parts of clean, hard, durable crushed rock or gravel, free from dust, soft particles, loam, vegetable or other deleterious matter, and passing when dry a screen having one-half (½) inch openings and retained on a screen having one-quarter (¼) inch openings. In no case shall aggregate for wearing course containing frost or lumps of frozen material be used.

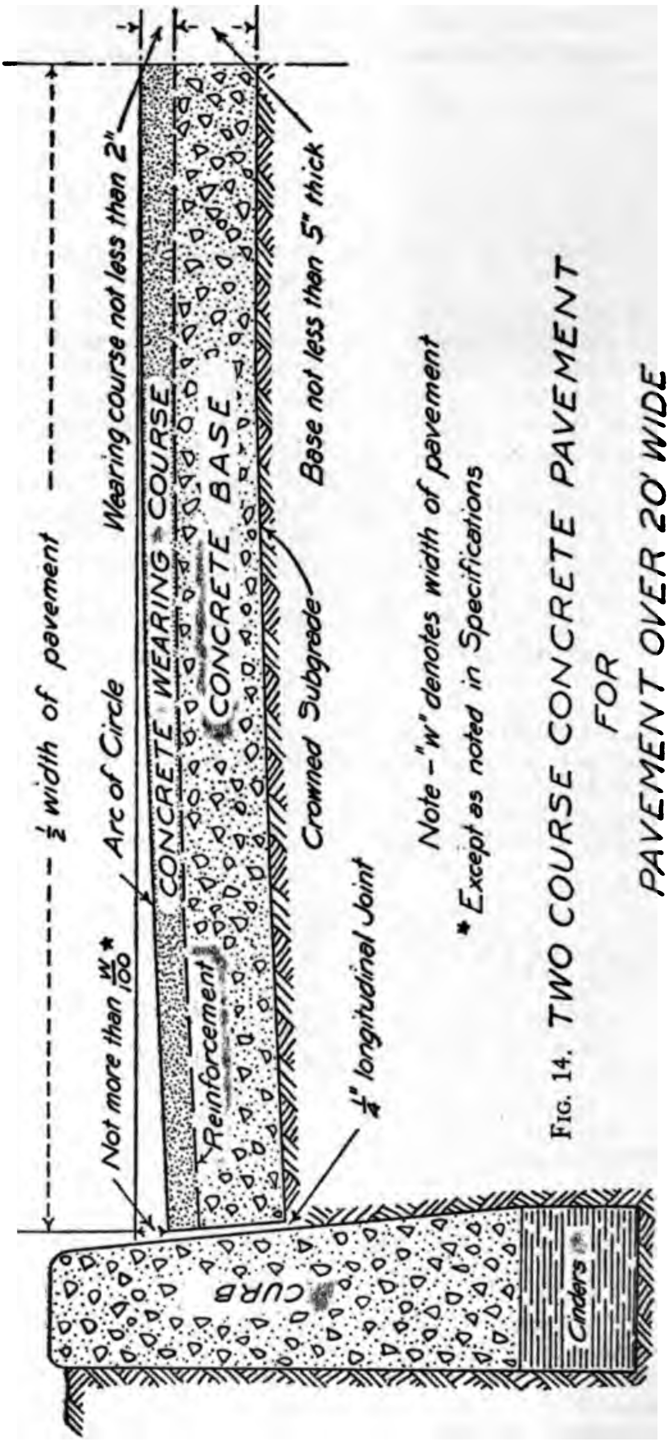

FIG. 14. TWO COURSE CONCRETE PAVEMENT FOR PAVEMENT OVER 20' WIDE

5. NATURAL MIXED AGGREGATE: Natural mixed aggregate shall not be used as it comes from deposits, but shall be screened, and used as specified.

6. WATER: Water shall be clean, free from oil, acid, alkali or vegetable matter.

7. REINFORCEMENT: Concrete pavements twenty (20) feet or more in width shall be reinforced with metal fabric. All reinforcement shall be free from excessive rust, scale, paint or coatings of any character which will tend to destroy the bond. All reinforcement shall develop an ultimate tensile strength of not less than 70,000 pounds per square inch and bend 180° around one diameter and straighten without fracture.

8. JOINT FILLER: Joint Filler shall consist of prepared felt or similar material of approved quality having a thickness of not less than one-eighth (1/8) nor more than one-quarter (1/4) inch.

9. JOINT PROTECTION PLATES: Soft steel plates for the protection of the edges of the concrete at transverse joints shall be not less than two and one-half (2 1/2) inches in depth and not less than one-eighth (1/8) nor more than one-quarter (1/4) inch average thickness. The plates shall be of such form as to provide for rigid anchorage to the concrete. The type and method of installation of joint protection plates shall be approved by the engineer.

10. SHOULDERS. Materials for the construction of shoulders shall be approved by the engineer.

II. GRADING

11. DEFINED: The term "grading" shall include all cuts, fills, approaches and all earth moving for whatever purpose where such work is an essential part of or necessary to the prosecution of the contract. When, to bring the surface to grade, a fill of one (1) foot or less is required, the area shall be thoroughly grubbed. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be removed and the space refilled with suitable material.

12. ENGINEER'S STAKES: Stakes will be set by the engineer for center line side of slopes, finished grade and other necessary points properly marked for the cut or fill.

13. EXCESS MATERIAL: Excess material shall be disposed of as directed by the engineer, the free haul not to exceed..................feet.

14. OVER-HAUL: Materials hauled a greater distance than the free haul from the place of excavation shall be paid for at the rate of............ cents per cubic yard for each additional....................... feet.

15. FILLS: Embankments shall be formed of earth or other approved materials and shall be constructed in successive layers, the first of which shall extend entirely across from the toe of the slope on one side to the toe of the slope on the other side, and successive layers shall extend entirely across the embankments from slope to slope. Each layer, which shall not exceed one (1) foot in depth, shall be thoroughly rolled with a roller weighing not less than five (5) tons nor more than ten (10) tons before the succeeding layer is placed. The roller shall pass over the entire area of the fill at least twice.

The sides of the embankment shall be kept lower than the center during all stages of the work and the surface maintained in condition for adequate drainage. The use of muck, quicksand, soft clay or spongy material which will not consolidate under the roller is prohibited.

When the material excavated from the cuts is not sufficient to make the fills shown on the plans the contractor shall furnish the necessary extra material to bring the fills to the proper width and grade. When the earth work is completed the cross section of the road shall conform to the cross sectional drawings and profile shown in Figure 14, page 198.

16. SLOPES: All slopes must be properly dressed to a line given by the engineer.

17. FINISHED GRADE: When the grade line is approached the final grade stakes will be set, for which sufficient notice must be given to the engineer.

Note: (In excavating cuts it is considered advisable, when the line of the sub-grade is approached, to compact the remaining material by rolling. The depth of material left in the cut to be compressed to the finished grade by rolling, will depend upon the character of the material.)

III. DRAINAGE

18. DRAINAGE: The contractor shall construct tile or other drains as shown in the drawings attached hereto. Tile to be laid in the trench at least .... (........) inches wide and .... (..........) feet deep below the top of the adjacent curb. Such trench shall be back filled with crushed stone or pit run gravel with sand removed which, after light tamping, shall be .... (.........) inches in depth.

19. CATCH BASINS: All catch basin and manhole tops and all covers of openings of any kind shall be readjusted to the grade by the contractor at his expense.

IV. SUB-GRADE

20. CONSTRUCTION: The bottom of the excavation or the top of the fill, when completed, shall be known as the sub-grade and shall be at all places true to the elevation as shown on the plans attached hereto.

The street shall be graded from curb to curb to the proper sub-grade to permit of specified thickness of paving materials being laid to bring the finished surface of the pavement to the lines and grades as shown on the plans. The sub-grade shall be brought to a firm, unyielding surface by rolling the entire area with a self-propelled roller weighing not less than ten (10) tons, and all portions of the surface of the sub-grade which are inaccessible to the roller shall be thoroughly tamped with a hand tamp weighing not less than fifty (50) pounds, the face of which shall not exceed one hundred (100) square inches in area. All soft, spongy or yielding spots and all vegetable or other objectionable matter shall be entirely removed and the space refilled with suitable material.

Where considered necessary, or of assistance in producing a compact, solid surface, the sub-grade, before being rolled, shall be well sprinkled with water.

When the concrete pavement is to be constructed over an old roadbed composed of gravel or macadam, and the concrete is to be wider than the old gravel or macadam road, the latter shall be entirely loosened and the material spread for the full width of the roadbed and rolled. All interstices shall be filled with fine material, and rolled to make a dense, tight surface of the roadbed.

21. ACCEPTANCE: No concrete shall be deposited upon the sub-grade until it is checked and accepted by the engineer.

22. COMPLETION: Upon the sub-grade thus formed shall be laid the concrete pavement as shown in Figure 14, page 198.

V. FORMS.

23. MATERIALS: The forms shall be free from warp, of sufficient strength to resist springing out of shape, and shall be equal in width to the thickness of the pavement at the edges. Wooden forms shall be of not less than two (2) inch stock, and shall be capped with two (2) inch angle iron.

24. SETTING: The forms when required shall be well staked or otherwise held to the established line and grades, and the upper edges shall conform to the established grade of the street.

25. TREATMENT: All mortar and dirt shall be removed from the forms that have previously been used.

VI. PAVEMENT SECTION

26. WIDTH, THICKNESS OF CONCRETE AND CROWN: The concrete pavement shall be...................... (.........) feet wide from face to face of curb. The base of the concrete pavement shall be .... (.........) inches in depth at the center and .... (.........) inches in depth at the sides. The wearing course shall be of..................... (.........) inches uniform thickness. The finished surface shall conform to the arc of a circle as shown in Figure 14, page 198.

Note: (The minimum thickness of the concrete base shall be not less than five (5) inches and the minimum thickness of the wearing course shall be not less than two (2) inches. When pavements twenty (20) feet or less in width are to be built on approximately level ground and a flat sub-grade is to be used, sufficient fall for drainage at the sides of the pavement along the curb shall be provided by giving the roadbed the same grade as that proposed for the gutter. The crown of all pavements shall not be more than one-one-hundredth (1/100) of the width except, when deemed advisable by the engineer, the crown of a pavement built on a crowned sub-grade may be increased to one-fiftieth (1/50) of the width to provide sufficient fall for drainage along the sides of the pavement at the curb.)

VII. JOINTS

27. WIDTH AND LOCATION: Transverse joints shall be not less than one-quarter (¼) inch nor more than three-eighths (⅜) inch in width and shall be placed across the pavement perpendicular to the center line, not more than thirty-five (35) feet apart. A longitudinal joint not less than one-quarter (¼) inch wide shall be constructed between the curb and the pavement. All joints shall extend through the entire thickness of the pavement and shall be perpendicular to its surface.

28. PROTECTION OF JOINTS: The concrete at transverse joints shall be protected with soft steel joint protection plates, which shall be rigidly anchored to the concrete. The installation of the metal protection plates shall meet with the approval of the engineer. The surface edges of the metal plates shall conform to the finished surface of the concrete, as shown in Figure 14, page 198.

All joints over one-quarter (¼) inch high or one-half (½) inch low shall be removed.

29. JOINT FILLER: All joints shall be formed by inserting during construction and leaving in place the required thickness of joint filler, which shall extend through the entire thickness of the pavement.

VIII. MEASURING AND MIXING

30. MEASURING MATERIALS: The method of measuring the materials for the concrete, including water, shall be one which will insure separate and uniform proportions of each of the materials at all times. A bag of Portland cement (94 pounds net) shall be considered one (1) cubic foot.

31. MIXING: The materials shall be mixed to the desired consistency in a batch mixer of approved type and mixing shall continue for at least forty-five (45) seconds after all the materials are in the drum. The drum shall be completely emptied before mixing successive batches. The drum of the mixer used shall revolve at a speed not less than the minimum nor more than the maximum number of revolutions shown in the following table:

Rated capacity cu. ft. unmixed material.	Capacity bags of cement 1:2:3 mix.	Revolutions per minute of drum. Min.	Max.
7 to 11	1	15	21
12 to 17	2	12	20
18 to 23	3	12	20
24 to 29	4	11	17
30 to 33	5	10	15

32. RETEMPERING: Retempering of mortar or concrete which has partially hardened, that is, mixing with additional materials or water, shall not be permitted.

33. CONSISTENCY: The materials shall be mixed with sufficient water to produce a concrete which when deposited will settle to a flattened mass but shall not be so wet as to cause a separation of the mortar from the coarse aggregate in handling.

34. CEMENT REQUIRED: A cubic yard of concrete base in place shall contain at least one and four-tenths (1.4) barrels of cement and a cubic yard of wearing course in place shall contain at least two and ninety-seven-hundredths (2.97) barrels of cement.

The engineer shall compare the calculated amount of cement required according to these specifications and plans attached hereto with the amounts actually used in each section of concrete between successive transverse joints, as determined by actual count of the number of bags of cement used in each section. If the amount of cement used in any three adjacent sections (between transverse joints) is less by two (2) per cent, or if the amount of cement used in any one section is less by five (5) per cent than the amount hereinbefore specified, the contractor agrees to remove all such sections and to rebuild the same according to these specifications, at his expense.

IX. REINFORCING

35. REINFORCING: Concrete pavements twenty (20) feet or more in width shall be reinforced. The cross-sectional area of the reinforcing metal running parallel to the center line of the pavement shall amount to at least 0.038 square inch per foot of pavement width and the cross-sectional area of reinforcing metal, which is perpendicular to the center line of the pavement, shall amount to at least 0.049 square inch per foot of pavement length.

Reinforcing metal shall be placed between base and wearing course and

shall not be less than two (2) inches from the finished surface of the pavement and otherwise shall be placed as shown on the drawings. The reinforcing metal shall extend to within two (2) inches of all joints, but shall not cross them. Adjacent widths of fabric shall be lapped not less than four (4) inches.

X. PLACING CONCRETE

A. CONCRETE FOR BASE

36. PROPORTIONS: The concrete shall be mixed in the proportions of one (1) bag of Portland cement to not more than two and a half ($2\frac{1}{2}$) cubic feet of fine aggregate, and not more than four (4) cubic feet of coarse aggregate, and in no case shall the volume of the fine aggregate be less than one-half ($\frac{1}{2}$) the volume of the coarse aggregate.

37. PLACING CONCRETE: Immediately prior to placing the concrete, the sub-grade shall be brought to an even surface. The surface of the sub-grade shall be thoroughly wet when the concrete is placed.

After mixing, the concrete shall be deposited rapidly in successive batches upon the sub-grade prepared as hereinbefore specified. The concrete shall be deposited to the required depth and for the entire width of the pavement, in a continuous operation, between transverse joints, without the use of intermediate forms or bulkheads.

The concrete shall be brought to a comparatively even surface, the thickness of the wearing course, below the established grade of the pavement. Workmen shall not be allowed to walk on the freshly laid concrete, and if sand or dust collects on the base it shall be removed before the wearing course is applied. The reinforcing metal shall be placed upon and slightly pressed into the concrete base immediately after it is placed.

In case of a breakdown, concrete shall be mixed by hand to complete the section, or an intermediate transverse joint placed, as hereinbefore specified, at the point of stopping work. Any concrete in excess of that needed to complete a section, at the stopping of work, shall not be used in the work.

B. CONCRETE FOR WEARING COURSE

38. PROPORTIONS: The mortar for the wearing course shall be mixed in the manner hereinbefore specified in the proportion of one (1) bag of Portland cement and not more than two (2) cubic feet of "Aggregate for Wearing Course" hereinbefore specified.

39. PLACING: The wearing course shall be placed immediately after mixing and in no case shall more than forty-five (45) minutes elapse between the time that the concrete for the base has been mixed and the time the wearing course is placed.

40. FINISHING: The wearing course shall be struck off by means of a template or strike board, which shall be moved longitudinally or crosswise of the pavement. Concrete adjoining the metal protection plates at transverse joints shall be dense in character and any holes left by removing any device used in installing the metal protection plates shall be immediately filled with a mortar composed of one (1) part Portland cement to not more than two (2) parts of fine aggregate.

After being brought to an established grade with the template or strike board, the concrete shall be finished from a suitable bridge, no part of which shall come in contact with the concrete. The concrete shall be finished with a wood float in a manner to thoroughly compact it, and produce a surface free from depressions or inequalities of any kind. The finished surface of the pavement shall not vary more than one-quarter ($\frac{1}{4}$) inch from the true shape.

XI. PROTECTION

41. CURING AND PROTECTION: **Excepting as hereinafter specified, the surface of the pavement shall be sprayed with water as soon as the concrete is sufficiently hardened to prevent pitting, and shall be kept wet until an earth covering is placed. As soon as it can be done without damaging the concrete, the surface of the pavement shall be covered with not less than two (2) inches of earth or other material which will afford equally good protection, which cover shall be kept moist for at least ten (10) days. When deemed necessary or advisable by the engineer freshly laid concrete shall be protected by a canvas covering until the earth covering can be placed.**

If at the time the pavement is laid, or during the period of curing, the temperature during the daytime drops below 50 degrees Fahrenheit, sprinkling and covering of the pavement shall be omitted at the direction of the engineer.

Under the most favorable conditions for hardening, in hot weather, the pavement shall be closed to traffic for at least fourteen (14) days, and in cool weather for an additional time, to be determined by the engineer.

The contractor shall erect and maintain suitable barriers to protect the concrete from traffic, and any part of the pavement damaged from traffic or other causes occurring prior to its official acceptance shall be repaired or replaced by the contractor, at his expense, in a manner satisfactory to the engineer. Before the pavement is thrown open to traffic the covering shall be removed and disposed of as directed by the engineer.

42. TEMPERATURE BELOW 35 DEGREES FAHRENHEIT: If at any time during the progress of the work the temperature is, or, in the opinion of the engineer, will within twenty-four (24) hours drop to 35 degrees Fahrenheit, the water and aggregates shall be heated and precautions taken to protect the work from freezing for at least ten (10) days. In no case shall concrete be deposited upon a frozen sub-grade.

XII. SHOULDERS

43. CONSTRUCTION: Where shoulders are required they shall be built upon the properly prepared sub-grade as shown on the cross sectional drawing, Figure 12, page 182. The work shall be done to the entire satisfaction of the engineer.

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